RUDIMENTARY TREATISE

ON THE

DRAINAGE

OF

TOWNS AND BUILDINGS.

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RUDIMENTARY TREATISE

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DRAINAGE

OF

TOWNS AND BUILDINGS:

SUGGESTIVE OF

SANATORY REGULATIONS

THAT WOULD CONDUCE TO THE

HEALTH OF AN INCREASING POPULATION.

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ERRATA.

Page 6, fourth line from bottom, *for* "of subsequent conveyance" *read* "or subsequent conveyance."

" 52, fifteenth line from bottom, *for* "to which water derived from such strata as are here described," *read* "by which water derived from such strata as are here described, is affected, are certainly likely," &c.

DRAINAGE.

DIVISION II.

DRAINAGE OF TOWNS AND STREETS.

SECTION I.

Classification of Towns according to Position and Extent.—Varieties of Surface Levels and Inclinations.

149. According with our definitions (Part I. p. 5), we propose to treat of the *supply* of *water* to *towns* and *buildings* as a branch of the general subject of *Drainage*, since the purposes of the art cannot be effected without an adequate and regulated supply of water by a combination of natural and artificial agencies, the extended control over which constitutes the purpose of water-supply for all highway, manufacturing, and domestic uses.

150. The means of obtaining water for towns, and of conducting the drainage matters from them vary, mainly, according to their position with reference to the sources of water; and, in a subordinate degree, according to their superficial extent. The sources being those already enumerated in our first Part, viz., rivers, rains, and springs, the command of one or more of these will be presented as the most economical means of deriving the necessary supply for each town under consideration. Towns situated on the banks of tidal

B

rivers, or in near proximity to them, may be usı sufficiently supplied from these sources, unless s parts of the district extend upward to such eleva above the river-level that the raising of this supply quires expensive artificial power; in which case spr at higher levels may be advisably resorted to, or drainage waters from superior lands may be so ducted as to assist the supply. Towns which are distant from rivers are commonly entirely depend upon springs or drainage waters for their artifi supply.

151. The refuse matters to be discharged f towns and buildings, consisting of the disintegr materials of street paving and roads; of superflu rain water; of excrementitious matters, solid and liq of the waste products of combustion; and of the re of animal and vegetable substances; besides the var waste matters used in manufactures require arran ments of different kinds to be provided with regard the purposes to which these matters may be usef applied. For such discharges of these matters as to take place through subterranean channels, one p ciple is, however, common to all, viz.: that the rec tacle to which they are conducted must be situated level somewhat lower than that from which they forwarded. The arrangements for this purpose therefore, be varied according to the nature of the of the town. If this be low in relation to the rounding country, and level, the refuse may be in ferently collected within or without the town, with, h ever, the advantage in the latter plan of avoiding s exposure of the decomposed matters as tends to lute the atmosphere, and at the same time saving tance in the transfer of such portions of those mat

as are destined for agricultural uses. If the site of the town be a valley with lower ground in the midst of it than is found anywhere without its limits, the readiest point of collection will be the lowest level in the town itself at which the drainage can be united, and artificial power will be required to distribute such matters as are intended for agricultural purposes around the higher ground outside. From towns which occupy elevated sites, having lower lands around them, the refuse matters and drainage waters should be conducted away at once, or, if found necessary to collect them, a point or points should be selected for this purpose altogether beyond the limits of the town itself.

152. In the several cases here supposed, the question of disposing of the refuse matters should be treated without any reference whatever to the presence of a river through or contiguous to the town, except upon the single consideration that such river, being in all probability situated at the lowest level of the site, may afford facilities, after the refuse has been collected in reservoirs near its banks, for its conveyance in suitable barges or vessels towards the higher lands for which some portion of this refuse is ultimately destined. Former practice in the art of town-draining has indeed regarded the one question of river or no river, as the grand determinal one for the disposal of drainage and refuse matters. How to get rid of the animal ordure created within the walls of a town, was formerly deemed to be satisfactorily answered provided a river flowed beneath, and offered a tide to wash away in boundless wastefulness those matters which, properly applied, will endow barren lands with the richest fertility.

153. Although reluctant to dwell upon the trite subject of the *importance* of draining, we claim attention

to this great leading principle in the drainage of town and buildings, viz., that the ultimate economy of th art comprehends two distinct purposes, whereof th second—the disposal and utility of the refuse matters— is little less in importance than the first—the discharg of these matters from the dwellings and highways c men. And the accomplishment of this second purpos involves the beneficial appropriation of refuse matter so as to make them actually productive, and avoid in terference with those healthy uses of inland waters fo which they are properly adapted. In illustration c this principle we will endeavour to estimate the valu for agricultural purposes of the excrementitious matter flowing from a town, from which estimate the per nicious effects of discharging those matters into th courses whence the supply of water is derived for th several uses of the population may be readily inferred.

154. The value of manures as promoters of vegeta tion is known to result from their possession of th essential element, nitrogen, in the form of ammoni with the subordinate properties of alkalies, phosphates and sulphates. Now, the experiments of Boussingaul and Liebig have furnished us with the means of esti mating the quantity of nitrogen contained in the excre ments of a man during one year, at 16·41 lbs., upo probable data, and also that this quantity is sufficien for the supply of 800 lbs. of wheat, rye, or oats, or c 900 lbs. of barley. "This is much more than it i necessary to add to an acre of land, in order to obtai with the assistance of the nitrogen absorbed from th atmosphere, the richest crops every year. By adoptin a system of rotation of crops, every town and farr might thus supply itself with the manure, which, beside *containing the* most nitrogen, contains also the mos

phosphates. By using, at the same time, bones and the lixiviated ashes of wood, animal excrements might be completely dispensed with on many kinds of soil. When human excrements are treated in a proper manner, so as to remove this moisture, without permitting the escape of ammonia, they may be put into such a form as will allow them to be transported even to great distances."* Making reasonable allowance for the reduced quantity produced by children, we shall be safe in assuming the nitrogen thus resulting from any amount of population to be equal to the supply required for affording 2 lbs. of bread per diem for every one of its members! Or assuming an average of 600 lbs. of wheat to be manured by each individual of the population of London; and taking this at two millions, for a rough calculation, the manure thus produced is sufficient to supply the growth of wheat of a total weight of 1200 millions of pounds, or 535,714 tons. The total manuring matters, solid and liquid, produced in a town, allowing for those which are produced in manufactories and sewage water, are probably equal in weight to one ton annually for each member of the population, or two millions of tons produced in the metropolis.

155. That this vast quantity of manure should be made available for agricultural production is a principle which cannot be denied, and which is properly limitable only by the consideration of expense as weighed against the value of the results. The expense will be made up mainly of three items, viz., of the *collection*, of the *raising*, and of the *distribution* of the refuse matters. The collection being an item common to all methods of disposal, will not be chargeable entire in any comparative estimate, but as modified by the peculiarities in the

* Liebig.

collection of which the plan is susceptible. The cost of raising is of course wholly chargeable to a system of artificial dispersion, as distinguished from the prevailing modes of self-discharge into low channels, but the former system will be debited only with the excess of expense (if any), beyond that incurred by the present methods of distributing the manuring matters for use upon the land. The cost of each of these works, however, may be reduced to a minimum by skilful arrangements, and our experience is yet insufficient to enable us to determine these with that precision which further practice will secure, or to estimate their total with the exactness necessary for forming a just comparison between the present and the proposed methods.

156. In a subsequent part of our work we propose to consider the items of cost in carrying out an efficient system of town-drainage; being satisfied at this stage of our subject in declaring the fundamental principle that the refuse of a town, including not only excrementitious, but all other waste matters and sewage, is far too valuable to be thrown away; and that the question of its appropriation should be made dependant only upon rules of a liberal economy, which ought, moreover, to be severely criticised before admitted to practical consideration.

157. The palpable inference from this principle is, as already stated, that the contiguity and position of a river, with reference to a town, have no necessary connection with the arrangement of its drainage beyond the facilities which may be thus afforded for the passage or subsequent conveyance of the sewage matters for their ultimate disposal. For it is quite certain that no correct general views of town-drainage can prevail *while* we continue to regard a river as the natural and

suitable trunk sewer into which all collateral and main courses of brickwork are to discharge their fœtid contents, which, according to the state of the river, are either immediately spread upon its banks to contaminate the air of the town, or duly infused in its waters, to be afterwards exposed with the same vicious effects.

158. From the principles here laid down, it will be understood that in the twofold purposes of the drainage of towns, viz., the supply of water, and the discharge and disposal of the refuse matters, the relative levels of the town, with the adjacent districts, and of the several portions of the town with each other, are the main considerations upon which the peculiar methods to be adopted in each case are determinable; but it will also be evident that, generally, those surfaces which are the most favourable for an economical water supply are the least so for the ready disposal of refuse matters, and the converse is equally true; those surfaces which present facilities for dispersing drainage-matters being commonly the least accessible to water.

159. Thus the flat districts on the margins of rivers and inland streams of adequate capacity are the most favourable sites for towns for the supply of water, but for drainage they are the least so; since the main channels or sewers are required to be laid at low levels, and the raising of their contents for use upon the neighbouring lands, which are probably much higher, becomes a very expensive process. On the other hand, a town on a hill-top is the most readily and cheaply drained; but its supply with water, whether from springs, rivers, or surface drainage—all at lower levels—is a work of great and constant cost.

160. Let us consider the several kinds of site which towns may occupy.

First.—A plain or flat surface, with surrounding

country of similar character. *Water* from rivers, springs, or from the surface of lands in the neighbourhood. Artificial power will be probably required to raise the water, however derived. The *drainage matters* must be conducted into one or more main sewers, and raised by artificial power for dispersion upon the land.

161. *Second.*—A plain or flat surface, with surrounding country rising from the town. Unless well situated with regard to a river, the supply of *water* will probably be the most economically obtained from springs on the hills, or from the collection of the waters which accumulate upon their surface. The *drainage matters*, if destined for the higher lands, should be generally conducted by mains towards the outskirts of the town, and the question of levels will evidently derive additional importance from the necessity of raising the sewage to levels naturally above that of the town itself.

162. *Third.*—A plain or flat surface, with surrounding country falling from the town. The supply of *water* will almost inevitably require a constant expenditure of artificial power, while the *drainage matters* may be collected in main sewers, and, in all probability, dispersed without any application of power, by the force of their own gravity.

163. *Fourth.*—An inclined surface on the side of a hill. *Water* will be derivable probably from several sources. If a river flow at the base of the site, the lower parts of the town will be most economically supplied from it, while for the higher the surface water from lands above or springs will be the most readily available. The general system of collecting and distributing the drainage-matters will be chiefly dependant upon the localities where they are intended to be ultimately disposed of. If these be on the lower part of the hill, the

method will be very simple, requiring only that main sewers be laid at the base of the town, from which the sewage may be distributed without any application of artificial power. But if the disposal of the sewage be inevitably desired on the lands above the town, the site constitutes one of the least favourable for economical drainage, which will require a constant expenditure of artificial power.

A river valley and a hill-top will evidently present a repetition or duplication of similar features to those here described, the only limitation in the resemblance being that in the case of a town on the summit of a hill the water supply will, most probably, be derivable only from lower sources by artificial power.

In these sketches the general superficial features of the site are of course only referred to. Intermediate undulations which may exist will affect the determination of the details of any arrangement of channels designed for serving the drainage of the town.

164. With reference to the artificial power which may be required for the supply of water, or the discharge of the drainage matters; if a tidal river can be commanded, it becomes a question of the highest importance whether this cannot be, and, if so, in what way made available as a source of the power required. And another question deserving the most attentive consideration is, whether the ebb tide may not be rendered efficient in aiding the discharge of the sewage where the fall is inadequate to insure its self-discharge.

165. As a general principle in town drainage, however, it should be so arranged and conducted as to require no artificial supply of water. The surface water should always be made sufficient to carry away all refuse matters, solid as well as liquid. Two reasons

exist for this: first, the economy of the water, which in many cases is a paramount, and in all should be a leading, consideration; and, secondly, the dilution of the sewage with any unnecessary liquid involves more capacious arrangements for its diffusion, and in most instances an extravagant amount of power to raise it.

166. The utmost economy of water for draining purposes can be secured only when a sufficient inclination in the sewers can be obtained. The methods of making a fall the most effectual are, therefore, deserving of the most careful attention in every scheme for town-drainage. The application of the tidal waters for assisting the discharge of the sewage can consequently be entertained only with reference to the principal main sewers at the lowest level, and with such adaptation, if practicable, as will admit the subsequent separation of the proper sewage matters from the water thus introduced to aid their progress and discharge.

167. Although the rules here suggested should be kept in view as leading objects in all arrangements of town-drainage, they will in many cases be admissible in part only, owing to the reference to existing works which is imposed upon us. Thus, in all towns for the attempted drainage of which some arrangements or other have already been executed, our practical operations become doubly difficult, since we are constrained to endeavour to reconcile these with the improved details which correct principles induce us to prefer. By way of illustration, which will be found fully instructive, let us turn our attention to the works now in action upon and beneath the surface of our own metropolis, and consider how the principles here stated can be the best applied to improve the means of its drainage.

168. LONDON, standing upon a bed of clay, the

substrata to which, successively, are plastic clay, chalk, and gault, occupies a part of the valley through which the river Thames has its course. The site of the town in some places rises gently from the river, and at others is below the level of high water, extending in dead flat districts. For the principal part, however, the surface rises above the river, which has therefore come to be regarded as the natural and proper channel for all the drainage of the town, the main sewers having been arranged to discharge their contents into it. Indeed, so thoroughly is this purpose of the river recognised, that those who take a general view of the present "system" of metropolitan sewage, describe the Thames as the "*Grand Sewer of London.*"

169. Now, in order to make this method effective of only one of the true purposes of drainage, viz., the mere getting rid of the sewage matters—it is evident that the arrangement must be such, that the whole of these matters are duly collected in the buildings and streets, and delivered into the sewers; also, that these are so constructed and situated that the matters they receive shall pass as rapidly as possible, and certainly without any interruption that would amount to stagnation, into the main sewers, and that these again faithfully and promptly convey the sewage into the final receiver, the river. So far, however, from being fulfilled in their entirety, no one of these conditions is fully and satisfactorily discharged. Thus, in many parts of the town, the refuse matters are collected in holes beneath the houses, and removed only when these holes become filled, and the surrounding soil permeated to supersaturation. Some districts have no sewers or drains of any description; and again, of the sewers which are constructed, very — very few are

formed with a rate of declivity sufficient for the sel discharge of the sewage, while many of them are la *perfectly level*. Attempts are made in some distric to obviate the evils of insufficient declivity, by a flusl ing of water through the sewers, the water being, f this purpose, accumulated for a time, and then sudden released, so as to produce the effects of a powerful cu rent. Of these methods some details will be found a subsequent part of this treatise; but they can be r garded only as palliatives, and expensive ones, applyin moreover, to one only of the many imperfections of tl present system. The crowning defect, however, exis at the last stage of this machinery, where the outfal of the sewers into the river are so low, that their co tents are delivered at, or a little above, low-water lev The decomposing matters are consequently deliver upon the banks of the river, and left there to stagna and poison the atmosphere, and to be brought up wi the next tide for the thorough pollution of the wate This is an irremediable evil of the present arrangemer by which no adequate fall can be obtained for tl sewers, consistent with their discharge into the riv near the high-water level, the only position in whi the sewage could be effectually conveyed away fro the higher towards the lower districts. Into some these sewers the water of the tide is permitted to ent the immediate consequence of which necessarily is, th the discharge of the sewage is suspended, and the gas engendered by the decomposing matter within the sewe are driven back towards the town. The return of tl tide of course assists the outflowing of the contents the sewers to some small extent, but, notwithstandi this expedient for assisting the discharge, the sewe are found to require periodical cleansing by hand, tl

foul matters being raised to the surface in buckets, and conveyed away in carts.

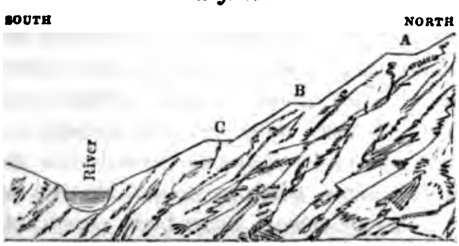
170. Of the many details of imperfection which mark the existing combination of arrangements constituting the sewage of the metropolis, all who have studied the subject are, to some extent, cognizant, and all are equally prepared to admit the magnitude of the several improvements which have been made within the last twenty years, and which tend to alleviate some of the most palpable evils of the prevailing system; but no thorough rectification can be effected until the correct principles of town-drainage are recurred to, and applied with such modifications as may enable us to make the best use of existing arrangements, without sacrificing objects of greater magnitude and importance.

171. All the real difficulties of the drainage of London have their origin in the great error of attempting to convert the river Thames into the common receiving sewer. In the attempt to accomplish this erroneous object, the sewage is brought down from the high lands, distances of miles, and heights of many feet, away from the very points where it should have been collected, and would be at once available for agricultural purposes. In the same attempt it has been found necessary to construct the lower ends of these sewers of immense size, in order to contain the accumulated sewage with which they are thus loaded. As the buildings have been extended, or a necessity has arisen for accommodating lower levels, the main sewers have been industriously removed, and rebuilt below their former position, and their capacity enlarged, to provide for the increased quantity poured into them. In the same obstinate attempt to pollute the waters of the river, miles of sewers have been constructed with-

out any declivity whatever, on an absolute leve which, as a necessary consequence, the refuse ma accumulate and solidify, until some happy rush of face-waters sends them onward to the common ceptacle, from which the population has the privi of afterwards supplying their personal and house wants. Now, let us banish the notion of turning river into a sewer, and consider how the sewage c be best arranged, supposing it had now to be don an entirely new work, and that we were unfettered any consideration of making the present subterrai structures available for the purpose.

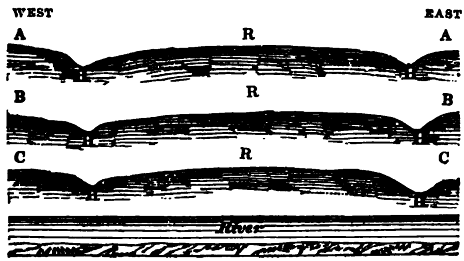
172. In the absence of any complete record of levels of London, we will assume the existence of veral ranges of elevation, running parallel, or nearly to the direction of the river, that is, generally east west. These ranges of elevation are of course in rupted at intervals by the ancient water courses, also by small ridges running north and south. Tl several features of the natural surface will detern the most economical courses for the general systen drainage. Thus the highest of the ranges (which will call A) should have a course of sewers for especial service of the districts above it; the next ra (B) should have another course of sewers to serve

Fig. 61.



district between A and B; the following range (C) should similarly be provided with its course of sewers to drain the district between B and C, and so on, as in the sketch, fig. 61. The general inclination, east and west, of each of these courses of sewers would be determined by the position of the ridges and hollows running north and south, as shown in fig. 62, where the highest points

Fig. 62.



of the several courses would be at R, and the lowest at H successively. By this arrangement, means would be obtained of collecting the sewage at each level or range of elevation, and disposing of it with the minimum power to be expended in raising it for manuring purposes.

173. The next great question to be determined would be, the most economical power that could be obtained at each of these points, H, for the purpose of raising the sewage for dispersion upon the land. For the lower level or range, the pumps could be worked by wheels driven by the tide of the river-water; and, in all probability, those for the upper levels could be worked, at any rate partially, by streams of water conducted, in suitable channels, from the uplands. At least, while we can command the immense water-power of the river, and of the accumulated surface drainage

from the large districts above, the best means of making this available for our purpose deserve all consideration, before we resort to the expensive power of steam. For the extended flat districts which bound the river, partly on the west, on the north east, and south, the tides of the river could also be made available, to a great extent, in doing the work required. The completion of the scheme would then want the details of the arrangements to be made suitable to the superficial features and relative levels of each part of the site, the construction, &c., of the sewers, and the machinery to be applied for raising and distributing the sewage; and we should finally be prepared to arrange the minor channels or drains, so as to subserve the efficient cleansing of every inch of the surface, and of every individual tenement in the town.

174. The arrangement here suggested will be the more peculiarly applicable, in proportion as the site resembles the general regularity of surface which we have supposed. In many parts of London there is no uniformity of inclination, and in others the rate of inclination is so trifling, that the surface may be treated nearly as a level. But the illustration we have referred to shows the general principle of the arrangement which would promote the greatest economy in the drainage of a town, the site of which resembles, in its principal features, the section given in fig. 61. In the application of this general system to London, *as it is*, these departures of superficial character from the theoretical regularity must of course receive due attention; and, beyond this, the existing arrangement of sewers must be carefully noted and consulted, with the view of rendering them, as far as possible, available as parts of the general plan. Until this existing arrangement is pre-

sentable to the eye, upon plans and sections of the metropolis that shall exhibit every peculiarity of surface and of subterranean structure, by which the details of the plan to be adopted would be affected, no correct estimate can be formed of the extent of modifications that would be required, nor how weighty may be the reasons for relinquishing, in some parts of the town, the scheme of a succession of levels or ranges of elevation. An acquaintance with these details will probably show the expediency of making use of some of the existing main sewers throughout the principal part of their length, but intercepting their contents before they reach the river, and forming tanks or other receptacles in which these matters should be collected.

175. The two objects—the public health and economy—being kept distinctly in view in the design and execution of these arrangements, it becomes necessary to show that the sewage can be collected, treated, raised, and dispersed, without any detriment to the first of these objects; and that these purposes can be effected at such cost as will be at least balanced by the advantage of applying the sewage as manure, or a material for irrigation.

176. The contents of the sewers, consisting of human and animal excrements, earthy matters carried down by the surface water from the roads and streets, with some portion of decayed vegetable and animal substances, &c., although at first partly solid, afterwards become reduced to a thick liquid state, of tolerably uniform quality. During the putrefaction of these matters, the ammonia they contain (and which is one of their useful constituents) is disengaged; and if this process take place in the open air, it is of course mingled with the atmosphere in the form of carbonate of ammonia, and

leaves the sewage in a less valuable condition. Now this volatile carbonate of ammonia may be fixed in many ways. Thus says Liebig:—"Gypsum, chloride of calcium, sulphuric or muriatic acid, and superphosphate of lime, are substances of a very low price; and if they were added to urine until the latter lost its alkalinity, the ammonia would be converted into salts, which would have no further tendency to volatilize. When a basin, filled with concentrated muriatic acid, is placed in a common necessary, so that its surface is in free communication with the vapours issuing from below, it becomes filled, after a few days, with crystals of muriate of ammonia. The ammonia, the presence of which the organs of smell amply testify, combines with the muriatic acid, and loses entirely its volatility, and thick clouds or fumes of the salt, newly formed, hang over the basin. In stables the same may be seen. The ammonia escaping in this manner is not only lost, as far as our vegetation is concerned, but it works also a slow, though not less certain, destruction of the walls of the building. For, when in contact with the lime of the mortar, it is converted into nitric acid, which dissolves gradually the lime. The injury thus done to a building by the formation of soluble nitrates has received (in Germany) a special name — salpeterfrass (production of soluble nitrate of lime). The ammonia emitted from stables and necessaries is always in combination with carbonic acid. Carbonate of ammonia and sulphate of lime (gypsum) cannot be brought together at common temperatures, without mutual decomposition. The ammonia enters into combination with the sulphuric acid, and the carbonic acid with the lime, forming compounds destitute of volatility, *and consequently* of smell. Now, if we strew the

floors of our stables, from time to time, with common gypsum, they will lose all their offensive smell, and none of the ammonia can be lost, but will be retained in a condition serviceable as manure. (Mohr.)" *

177. Chemistry thus supplies us with the means by which all the offensive and detrimental properties of the sewage may be suppressed, and all the useful properties safely retained. There is evidently no necessary reason why a tank or receptacle in which the sewage is collected and stored should be, in any respect, more disgusting to the senses, or injurious to the health of human beings, than a reservoir of the purest water.

178. Can the remaining question of *cost* be disposed of with equal satisfaction, so as to show that the application of the sewage to manuring purposes may be effected with due economy? Will the agricultural value of the sewage pay the expenses of applying it? We believe it may. These expenses will embrace the construction of the tanks or stores for the sewage, of the pumps and raising machinery, and the means of treating the sewage with gypsum or other agent, and of distributing it upon the lands to be served; but against the total, in a comparative estimate, would have to be placed the cost of the present partial removal of night-soil from cesspools, the immense additional cost incurred by the necessity of having immense sewers, the cost of outfalls into the river, and the expense of cleansing the present sewers by hand. Now, in order to form a rough estimate of these several expenses with which the present system is to be debited, we will assume the popula-

* "Chemistry in its Application to Agriculture and Physiology," by Justus Liebig. Edited by Drs. Playfair and Gregory. Fourth Edition, 1847, p. 189.

tion of the metropolis to be two millions, and the number of houses, 200,000, that is, ten persons to each house on an average; that half of these houses are still drained into cesspools, and that the cleansing of each of these costs one pound annually. We shall then have 100,000*l.* as the annual cost of removing the contents of the cesspools of the metropolis. The number of miles of sewers constructed during the ten years from 1833 to 1843, throughout the metropolis, was about 120, or, annually, twelve miles on an average; and the excess of capacity in these sewers, made necessary by the deficiency of declivity, and the great length to which they are extended, probably involved a cost, in construction, equal at least to 2000*l.* per mile. This item would thus amount to 24,000*l.* annually, in which the expense of outfalls to the river may be included. To these are to be added the expenses of cleansing the sewers by hand, which may be moderately computed at 10,000*l.* annually throughout the metropolis. We shall thus have an amount of 134,000*l.*, which would be annually saved in these items by the proposed system.

179. A very reduced estimate of the value, for manure, of the excreta of human beings (reduced avowedly for the sake of gaining public belief), represents it at 5*s.* for each person annually. The value of the produce of the population of London would thus be 500,000*l.* per annum. Admitting one-half of this to be now made available, we shall have the other half, amounting to 250,000*l.*, gained by the proposed mode of collection, and adding this to the 134,000*l.* estimated saving (178), we have a total of 384,000*l.* annually available for the expenses of construction and repair of apparatus, and current cost of collecting, raising, and treating the sewage of the metropolis. This sum will endow thirty-

eight stations with an annual income each exceeding 10,000*l.* for interest of capital in first construction and current expenses of working and treating. And this number of stations appears fully adequate to realize all the economy of power which can be attained by judiciously providing for several levels in each district of the metropolis.

180. In order to show that this rough estimate as to the value of the sewage, and the cost of applying it, is not formed upon fallacious data, calculated to induce an unfounded preference for the method recommended, we may refer to the high authority of the Superintending Inspectors under the General Board of Health, Messrs. Cresy and Ranger. Mr. Cresy, in reporting upon the present sanatory condition of the borough of New Windsor, and offering his official recommendations for its improvement, estimates the population at 10,200, and the annual value of the sewage manure at from 1000*l.* to 1500*l.* And for the first cost of the apparatus for distributing this manure, he allows an expenditure of 4000*l.*, being 3000*l.* for 10 miles of pipe, and 1000*l.* for pumping engine, &c. Mr. Ranger estimates the value of the sewage matters of the town of Uxbridge to be at least equal to 1700*l.* per annum, the population being 3219 (in 1841), or about 10*s.* for each person; and for the first cost of the distributing apparatus, he allows 3500*l.* In reporting upon the town of Eton, of which the population was 3526, in 1841, Mr. Cresy estimates the value of the excreta at 500*l.* annually, and the cost of main sewers and tanks for the sewage at 1000*l.*

181. These estimates of the value of sewage vary from 2*s.* to 10*s.* 6*d.* per individual, between which our average of 5*s.* is certainly a safe medium. And the

allowance for first cost of apparatus for pumping, &c., varies from about 6*s*. to 1*l*. 2*s*. per individual. If we assume 1*l*. as a safe average, the annual interest, at five per cent., upon two millions of pounds, being 100,000*l*., we shall have 284,000*l*. left for the current expenses of our thirty-eight stations, or about 7470*l*. each annually, which must be admitted to be a very liberal estimate of the cost of pumping and treating the sewage.

182. Of the current expenses of distributing the liquid sewage upon the land, and of first conveying it from the stations to the districts to be supplied, whether by a system of piping, or by vessels or carts, it will not be necessary to offer any estimate here. These duties will probably involve an expenditure which would have the appearance of being heavy, if not fairly compared with the cost now incurred in imperfect manuring on the one hand, and on the other, with the vastly increased value given by the application of the liquid sewage to the products of arable and pasture lands. When the costs and the results of the two methods can be, from actual and extended experience, placed thus in juxtaposition, we are justified in anticipating that a large balance of advantage and economy will appear incontestably due to the system of applying and distributing the liquid sewage as here described.

183. The multiplicity of stations necessary to carry out the scheme of ranges of elevation may appear to involve practical difficulties, and objections of a serious character, that should be adverted to, and their real value shown in contrast to the advantages which this arrangement offers. The primary consideration which must be satisfactorily fulfilled is, the practicability of accomplishing this method without any sacrifice of health, by the raising and distribution of the sewage a

and from the several stations. The treatment with gypsum, already alluded to, may, it is presumed, be carried on at such a cost as shall not impair the ultimate economy of the process, and in such a manner that no offence shall be committed against the most fastidious delicacy of sense. Indeed, the completion of the process would perhaps require that the gypsum should be administered either constantly, or at stated intervals, within the collateral or the main sewers, by which means all disengagement of foul gases would be prevented, and the sewage would arrive at the receiving tanks in an innocuous and fixed condition. But until this method is carried out, the tanks may be so covered in, and their contents excluded from association with the external air, as that the latter shall not suffer any contamination, and similarly the sewage, pumped up, may be distributed in closed pipes, or loaded into river or canal boats, or into wheeled vessels, so constructed of iron that the sewage, already purified in the tanks, shall be at once conveyed away, without exposure in the slightest degree. The great advantage, however, of effecting this purification at the earliest possible stage (and the only *perfect* system is that which shall provide for doing it in the drainage of each individual house) is too apparent to be disregarded or lightly estimated. It has been well remarked, that so long as our covered sewers are permitted to emit the noisome gases engendered by the putrefying matters within them from the air grates and gully holes into the streets, they remain, to all intents and purposes, *nuisances*, and are nearly as dangerous and offensive as if they were open sewers. And when it is remembered that these very gases, which bring pestilence and death to our poor population, would, if retained within the sewage, constitute its

most valuable properties, we surely find abundant reason for seeking the best practicable method of applying the purifying process before these dangerous properties are developed, and of transmitting the fructifying matters to our fields before their value has been thus grievously impaired.

184. Another objection which the system of ranges of elevation will probably meet with is, that the sewage matters cannot be made available at any great number of points within the town and its suburbs. This may be admitted. It is, indeed, very likely that no profitable use can be made of the sewage within some few miles of the metropolis; but it does not therefore follow that it can be more advantageously conveyed in sewers to the distant station, where it may, perhaps, be applied at once. If we had the materials for instituting a fair and exact comparison between the first cost of constructing and current expenses of maintaining, in a healthy condition, the deep and large sewers required for any system of sewage which is not mainly determined by the minor varieties of surface, and the expenses of transporting the sewage from many points by pipes or by river, railway or canal, with all the facilities we can now command for any general and extended system, the latter would be found to be recommended as strongly by its economy, as it undoubtedly is by its superior efficiency in subserving the health and well-being of the population. The economy of transmitting liquid matters in pipes is well known, and the cost has been estimated, by engineers, at 2½*d*. per ton for a distance of five miles, and to a height of 200 feet. This includes interest of capital and all current expenses. Railway tolls and canal dues may indeed be regulated *so as to* afford but little facility for the transmission of

manure at present; but wonderful modifications will be volunteered in these matters, so soon as the system becomes general, the demand for accommodation be increased, and the mechanical and chemical appliances for purifying and transporting the sewage rendered more ready and effective.

185. Any system of collection which attempts to concentrate the sewage at a few points must be attended with extravagance in one or more of three different ways. First, and constantly, in the enlarged capacity of sewers required for two reasons, viz., the great quantity to be conveyed, and the extra size needed to compensate for the deficiency of declivity. Secondly, in the greater distance over which the sewage has to be transmitted. Or, thirdly, in the greater cost of raising it from the level of the sewers to the high surface above it. Thus arise objections to the propositions which have been made for conducting the whole of the sewage of London to one point, situated at a distance of several miles eastward of the town, in which case retransmission would become necessary, in order to supply districts in all other directions. And, on the other hand, if it be collected at any point towards the north or north-west, where probably the greatest demand for it would be found, the reservoir would be necessarily constructed at a depth from the surface which would entail immense and needless expense in raising the sewage for application on the land.

186. Another important point in which the many-station system offers advantages, which the single-station system does not, is the facility for storing the sewage for any required time, until it may be required for agricultural use. It is well known that the ma-

nuring matters are required to be applied at certain seasons and intervals, according to the nature of the vegetation. If the sewage be collected in one reservoir, the size of it, in order to serve the true purpose of a reservoir or store-place, must be immense, almost to impracticability; but if divided, as proposed, between many points, tanks of moderate size would be amply sufficient to contain the accumulation of long intervening periods, while the facility of distribution would, moreover, probably induce the use of the sewage for varieties of culture, that would tend to equalize the demand for it.

187. Sewers are, properly, *mere passages* for the sewage, but they are so only while the matters sent into them are induced to continue moving by the declivity of the sewer, or by the artificial force of water, or other agent, to drive or carry them forward. Without one or other of these aids the large sewers we have been constructing are known to become reservoirs of sewage, or cesspools, in which, during dry seasons, the refuse matters remain decomposing for days and weeks, sending up the most pernicious gases into the drains and water-closets of the houses, and through the air-grates and gully-holes into the streets of the town. The system which adopts ranges of elevation and varieties of surface, as indications by which to lay small sewers with rapid declivities, and leading into tanks situated at short distances from each other, obviates these evils, by constructing the sewers so that they maintain their proper character of mere passages, and the tanks are made to perform the double purpose of storing and purifying the sewage. The chamber of the tank into which the sewers discharge may be trapped,

by turning down into water, so that no impure exhalations can possibly return along the sewer towards the houses and streets.

188. In adapting this arrangement to London, or any other town already provided with sewers, those in which sufficient fall exists may be retained and made to deliver into tanks at the lowest point of each range or district. But all sewers without fall, or with less than is sufficient for the rapid self-discharge of their contents, should be at once abandoned, and a separate system of sewers constructed, dipping into one or more tanks at the centre and other points of the flat district. As a general principle, to be very reluctantly departed from, the surface-water and waste household-waters should be admitted as the only dilutants of the solid sewage. Artificial scouring or flushing of the sewers may be regarded as an expensive and troublesome correction of some of the evils occasioned by deficient declivity, but one sometimes attended with a most mischievous consequence, viz. — the forcing up of the sewage into the streets from some of the lower sewers, which become surcharged with the flushing water during the process. Another expedient which is occasionally recommended, and in some cases practised, the scouring by admitting the tidal water of the river, is inapplicable to any method which purposes to preserve the sewage for agricultural uses; and must be admitted to have the effect of thoroughly defiling the lower banks of the river at which the discharge takes place.

189. Having thus shown that the true principle upon which towns should be classified in order to consider the best system of arranging their general drainage, is that of ranges of elevation and varieties of surface without any reference to contiguous rivers or water-

courses, and having, in support of this principle, stated that the system of conducting the sewage to the river, besides wasting that which is really of great value and poisoning the water, necessitates immense mis-expenditure in large and deep sewers, it will be desirable, before closing this section, to cite some further authority as to the value of sewage manure, and notice the plans which have been proposed for applying that produced in London; and also to quote some few instances of the works which have been executed to provide for delivering the sewage of London into the river Thames.

190. The sewage of the city of Milan is collected in two concentric canals, the inner one of which is called the Sevese, and the outer the Naviglio, into one called the Vettabbia, which flows from the southern part of the city, and, after a course of about ten miles, discharges into the river Lambro. Throughout its course this stream of sewage is made to flow over a large extent of meadow-land, and is found to possess such valuable fertilizing properties that the deposit, which has to be periodically removed in order to preserve the level of irrigation, is bought by the neighbouring agriculturists, and esteemed an excellent manure. Some of the meadows, which are thus irrigated by the sewage-water of Milan, yield a net rent of 8*l.* per acre, besides paying taxes, &c. These meadows are mowed in January, March, April, and November for stable-feeding. They besides yield three crops of hay, viz.— in June, July, and August; and in September they furnish ample pasture for the cattle till the irrigation in the winter.

191. Mr. Smith, of Deanston, in reporting to the "Commissioners for inquiring into the State of Large *Towns and* Populous Districts," upon the "application

sewer-water to the purposes of agriculture," gave an eresting description of the method which has been opted for upwards of 30 years in applying the sewage-ter of part of Edinburgh to the irrigation of grass-ıd. "The sewer-water, coming from a section of : Old Town, is discharged into a natural channel or ook, at the base of the sloping site of the town, at ficient height above a large tract of ground extending vards the sea, to admit of its being flowed by ıvitation over a surface of several hundred acres. e water, as it comes from the sewers, is received into ıds, where it is allowed to settle and deposit the oss and less buoyant matter which is carried along the water, whilst it flows on a steep descent. From se tanks or settling ponds the sewer-water flows off the surface, at the opposite end to its entrance. The ter so flowing off still holds in suspension a large antity of light flocculent matter, together with the re minute *débris* of the various matters falling into the vers, and chiefly of vegetable and animal origin. The ter is made to flow over plats or plateaus of ground, med of even surface, so that the water shall flow as ıally as possible over the whole, with various de-ıations, according to circumstances; and it is found, practice, that the flow of water can easily be adjusted suit the declination." "The practical result of this plication of sewer-water is, that land, which let for-rly at from 40*s*. to 6*l*. per Scotch acre, is now let ıually at from 30*l*. to 40*l*., and that poor sandy land the sea-shore, which might be worth 2*s*. 6*d*. per e, lets at an annual rent of from 15*l*. to 20*l*. That ich is nearest the city brings the higher rent chiefly cause it is near and more accessible to the points ere the grass is consumed, but also, partly, from the

better natural quality of the land. The average value of the land, irrespective of the sewer-water application, may be taken at 3*l.* per imperial acre, and the average rent of the irrigated land at 30*l.*, making a difference of 27*l.*, but 2*l.* may be deducted as the cost of management, leaving 25*l.* per acre of clear annual income due to the sewer-water." Mr. Smith calculates that 17,920 gallons of sewage-water, containing 5 cwt. of dissolved and suspended matter, are equal in fertilizing power to 2½ cwt. of guano, or 15 tons of farm-yard manure; and he estimates the expense of the material and process, as applied to one acre of land, as follows:—

	£	*s.*	*d.*
Cost of manuring one acre of land with 17,920 gallons of sewer-water . .	0	12	9
2½ cwt of guano at 8*s.*	1	0	0
15 tons of farm-yard manure at 4*s.* . .	3	0	0

He further calculates that the comparative economy of the sewer-water manuring will increase with the greater quantity of each kind of manure applied; thus:—

Cost of manuring one acre of land with 35,840 gallons of sewer-water . .	0	16	6
5 cwt of guano at 8*s.*	2	0	0
30 tons of farm-yard manure at 4*s.* . .	6	0	0

192. Mr. G. Stephen in his "Essay on Irrigated Meadows," published in 1826, had previously described the system of sewer-manuring with commendation. Mr. Stephen says, "Edinburgh has many advantages over many of her sister cities, and the large supply of excellent spring-water is one of the greatest blessings to *her inhabitants*, both in respect to household purposes

and in keeping the streets clean; and, lastly, in irrigating the extensive meadows selected below the town by the rich stuff which it carries along in a state of semi-solution; where the art of man with the common shore water has made sand-hillocks produce riches far superior to anything of the kind in the kingdom, or in any country. By this water about 150 acres of grass-land, laid into catch-work beds, is irrigated, whereof upwards of 100 belong to W. H. Miller, Esq., of Craigintinny, and the remainder to the Earls of Haddington and Moray, the heirs of the late Sir James Montgomery, and some small patches to other proprietors. The meadows belonging to the last-mentioned noblemen, and part of the Craigintinny meadows, or what are called the old meadows, containing about 50 acres, having been irrigated for nearly a century, they are by far the most valuable, on account of the long and continual accumulation of the rich sediment left by the water; indeed, the water is so very rich, that the proprietors of the meadows lying nearest the town have found it advisable to carry the common shore through deep ponds, where the water deposits part of the superfluous manure before it is carried over the ground. Although the formation is irregular, and the management very imperfect, the effect of the water is astonishing; they produce crops of grass not to be equalled, being cut from four to six times a year, and given green to milk cows. The grass is let every year by public auction, in small patches, from a quarter of an acre and upwards, which generally brings from *24l.* to *30l.* per acre. This year (1826) part of the Earl of Moray's meadow gave as high as *57l.* per acre."

193. The results of experiments tried at Clitheroe, in Lancashire, showed that the fertilizing properties of

sewage water were nearly four times as great as those of common farm-yard manure. Mr. Thompson applied 8 tons of the sewage water to one acre, and 15 tons of the ordinary manure to another, and the produce of the former was as 1·875 to 1 of the latter. Comparing the produce with the weight of manure, the proportion of the one to the other will therefore be as 1·875 to ·532, or nearly fourfold.

194. The sewage-water of Mansfield, in Nottinghamshire, has been so applied to lands by the Duke of Portland, that with a preliminary expenditure of 30*l.* per acre, to put the land in a condition fit for irrigation, its annual value has been raised from 4*s.* 6*d.* to 14*l.* per acre. Mr. Dickinson treated some land at Willesden, in Middlesex, with liquid manure, derived from horses, and obtained fine crops of Italian rye grass, although the land had previously been deemed unworthy of cultivation. Mr. Dickinson obtained ten crops in twelve months. In the year 1846, the first crop (cut in January) yielded more than 4 tons per acre; the second gave nearly 8, and the fourth, cut in June, produced 12 tons per acre.

195. At Ashburton, where they have applied liquid manure for 50 years, and at other towns in Devonshire, the land thus treated produces grass at least a month earlier than lands not so treated, and is valued at 8*l.* to 12*l.* per acre, while land not so improved is considered worth only from 30*s.* to 40*s.*

196. One of the earliest, if not *the* earliest, of the suggestions for saving and applying the sewage of London appears to have emanated from Mr. John Martin, the artist, in the year 1828. Mr. Ainger, in 1830, published a plan for "preserving the purity of the water of the Thames," by constructing covered drains along the sides of the

river to receive the minor drainage, and Mr. Martin in July, 1834, presented to the select committee of the House of Commons, then inquiring into the state of the law respecting sewers in and near the metropolis, with a view to suggest amendments, a "Plan for improving the air and water of the metropolis by preventing the sewage being conveyed into the Thames, thereby preserving not only the purity of the air, but the purity of the water; and likewise for manure and agricultural purposes." The objects of this plan were described to be—"first, to materially improve the drainage of the metropolis; secondly, to prevent the sewage being thrown into the river, and to preserve in its pure state the water which the inhabitants are necessitated to use; thirdly, to prevent the pollution of the atmosphere by the exhalations from the river and the open mouths of the drains; and, fourthly, to save and apply to a useful purpose the valuable manure which is at present wasted by being conveyed into the river."

197. The details of the plan embraced the formation of a receptacle at Bayswater, on the north side of the Uxbridge Road, for the drainage of Kilburn, part of Paddington, Bayswater, &c., &c., and of another receptacle above Vauxhall Bridge to receive the contents of the present King's Scholars' Pond Sewer. For the body of the city, Mr. Martin proposed a grand sewer to commence at College Street, Westminster, and run parallel with the river, and to be extended to a convenient point near the Regent's Canal at the east end of London. And for the south side of the river, a similar plan was recommended, the sewer in this case to commence near Vauxhall Bridge, and pass along the bank of the river to Pickle-Herring Stairs, thence, branching off through Rotherhithe, to a convenient

spot adjoining the Grand Surrey Canal, where a grand receptacle should be constructed similar to that by the Regent's Canal on the north side of the river.

198. These grand sewers were proposed to be constructed of iron, the bed of them being on the same level with the shore, and following the inclination of the river about 7 in. per mile. The top of them to form quays, at least 2 ft. above the highest possible tide. To prevent the possibility of those sewers being burst by the accumulations of floods, they were to be provided with flood-gates; and to afford facility for inspecting, and, if necessary, cleansing them, light-iron galleries were designed to be suspended from the roof. The sewers were to be built up of iron, the bottom paved with brick, and the top arched with sheet iron, with wrought-iron ribs; the size of the sewers being on the average 20 ft. in depth and width, and the estimated cost of their construction 60,000*l.* per mile, including sewer, pier, or quay, strong quay-wall of cast-iron, towards the river, &c., &c. The whole length of the two sewers proposed was about 7½ miles. The description of the receptacles in which the sewage was to be collected will be best quoted from the proposer's "Plan" submitted to the committee.

199. "The grand receptacle at the end of this great covered sewer should be 20 yards deep, and 100 yards square, with a division down the centre, separating it into two compartments, each 50 yards in width, with a flood-gate at the inner angle of each compartment for the sewage to run in at; and at the opposite extremity, within about 13 ft. of the top, there should be an iron grating, 5 feet wide by 50 yards long, through which the lighter and thinner parts of the sewage would rise; *the heavier* and grosser parts would sink to the bottom,

and gradually fill up the base of the drain; when the gate should be closed, and the one leading into the second division of the receptacle opened. At the extremity of the receptacle, between the two compartments, there should be an engine to raise the manure into barges, and also to pump the water in case of extraordinary tide; in this way the expense of an extra receptacle for the water accumulating whilst the tide is up would be saved; this, however, would only be required in spring tide. The receptacle would be so firmly built, and covered with a roof of wrought iron, supported by cast-iron pillars, that a road could be made over it; or it might be built upon, and thus no room would be lost; and, that a particle of smell might not be allowed to escape, there should be a communication for the foul air to pass from the receptacle to the fire of the engine, which would then completely consume it."

200. Within the last three or four years a company has been organized, we believe under the original auspices of Mr. Martin, and promoted by Mr. Smith of Deanston, which proposed to carry into effect, for the general benefit of the metropolis, a plan for collecting the sewage by means of a receiving sewer which should cut the existing sewers at a mean distance of 620 yards from the river. Mr. Martin, the founder of the company however, objected to this, wisely preferring to receive the contents of the sewers near their outfall into the river. The Company referred to—the "Metropolitan Sewage Manure Company,"—under the advice of Mr. Smith, contemplated the "conveying of the sewage water of London, by means of a system of pumping engines and pipes, analogous to that of the great water companies, and thus distributing the fertilizing fluid

over the land in such manner and proportions as may be best adapted to the various kinds of field and garden cultivation." The proposals of the Company were eventually limited to an operation upon the sewage belonging to the King's Scholars' Pond Sewer, one of the principal sewers in Westminster, and with this reduced purpose an Act of Parliament was obtained for prosecuting the scheme in 1846. The contents of that sewer are to be collected in a well, suitably constructed, and to be raised from the well by pumps worked by steam engines, and carried in a main pipe some 10 or 12 miles in a western direction; branch pipes being provided for serving the manure to farms on either side of the main. When applied for irrigating grass land, the sewage is to be discharged from the service pipes into the channels prepared for that purpose. For manuring arable land it is proposed to adapt hose pipes to the service pipes, and throw the liquid manure in jets, the requisite pressure upon the pipes being produced by a stand-pipe, say 2 ft. in diameter, and 150 ft. high, the distribution being entirely conducted by the servants of the company, and the power of the steam engine being properly adjusted according to the quantity of liquid delivered at the extremities of the pipes.

201. During the inquiries upon this subject which were instituted by the Sewage Company, some proposals were elicited which differed considerably from those here referred to, and upon which the Company is now acting. Two of these may be noticed, which were examined by the select committee, appointed in 1846, to consider plans for the application of the sewage of the metropolis to agricultural purposes. It should be mentioned, that the original plan of the Metropolitan Sewage Manure Company embraced the

formation of reservoirs, in which the sewage was to be collected from the sewers, but these reservoirs were relinquished by the promoters of the bill, in consequence of the objection made against them by the owners and occupiers of land.

202. One of the proposals here alluded to was suggested by Mr. Wicksteed, and was to carry away the entire sewage of the metropolis, in a tunnel of from 8 ft. to 12 ft. in diameter, and at a depth of from 40 ft. to 80 ft. beneath the surface of the streets. This sewer was designed to commence at the Grosvenor Road, and pass easterly, through Westminster to the Strand, and continue on the south side of St. Paul's Church Yard, Cannon Street, &c., to the Commercial Road, thence under the River Lea, and in a straight line through the West Ham marshes, to a large reservoir and works, to be constructed in an angle between the western banks of Barking Creek and the northern banks of the Thames. The sewer-water was proposed to be raised by steam-engines from the receiving reservoir into other reservoirs, sufficiently elevated to permit the solid matters being deposited at a level above the Trinity high-water mark. From these reservoirs the solid matter would be periodically removed, dried by artificial means, and then compressed and packed for transmission by land or water. The liquid matter was to be discharged as worthless, at all states of the tide. Mr. Wicksteed calculated that engines would be required of an aggregate power equal to that of 1060 horses, and capable of raising, when worked at full power, 18,000,000 cubic feet to a height of 56 feet, in twenty-four hours, being considered equal to two and a half times the present ordinary quantity of sewer-water. The waste of the liquid

sewage contemplated in this scheme destroys the purpose of what was intended to be a simple method of collecting the contents of the existing sewers; but, as already insisted, no scheme can be admitted as having any pretensions to completeness which retains the defective sewers now constructed, without any, or with an inadequate descent, and leaves them as permanent reservoirs, in which the sewage undergoes entire putrefaction.

203. The other proposal which received the attention of the select committee, and to which we will allude, was suggested by Mr. Higgs, the patentee of some complete arrangements for the treatment of sewage matters. Mr. Higgs's patent is dated 28th of April, 1846, and the object is entitled, "The means of collecting the contents of sewers and drains in cities, towns, and villages, and of treating chemically the same; and applying such contents, when so treated, to agricultural and other useful purposes." The scheme comprises the construction of tanks or reservoirs for the sewage, with suitable buildings over them, in which the gases evolved are to be collected, condensed, and combined with chemical agents; and also an arrangement of spars or bars, on which the salts formed by this combination may crystallize. Apparatus is devised also for distributing the chemical agents over the mass of sewage, and the claims of the patentee extend to the use and application of them for the purpose of precipitating the solid animal and vegetable matters contained in the sewage, and of absorbing and combining with the gases evolved from it. "Hydrate of lime," or "slaked lime," and "chlorine gas," were the agents proposed to be employed for these purposes, and the solid matters were to be cut into suitable shapes, and dried ready for use.

The committee, however, did not feel justified in recommending these elaborate processes, in the then immature state of the public mind upon the subject.

204. Let us briefly glance at the magnitude of some of the sewer-works which have been constructed, in the extravagant attempt to convey the entire sewage of London into the river Thames, and to maintain the subterranean channels in a clean and healthy condition. The Irongate sewer, which was formerly the city ditch, varies in height from 6 ft. 6 in. to 11 ft., and in width, from 3 ft. to 4 ft. The Moorfields sewer is 8 ft. 6 in. by 7 ft., and at the mouth, 10 ft. by 8 ft.; and at the north end of the Pavement this sewer is 27 ft. below the surface. The Fleet ditch, which drains the land from Highgate southward, is partly formed in two distinct sewers, which run on each side of Farringdon Street; they are from 12 ft. to 14 ft. high, and each is 6 ft. 6 in. wide, yet they are liable to be flooded by the immense rush of waters from the northward, and a single storm will raise the water 5 ft. in height in both of them, almost instantaneously. The culvert constructed at the mouth of this sewer was severely injured, in 1842, by the flood consequent upon a thunderstorm. The Bishopsgate-Street sewer, which receives the drainage of Shoreditch and adjacent places, is 5 ft. by 3 ft., is sometimes overcharged, and returns the waters from the high ground.

205. The large sewers constructed in the Tower Hamlets Division are 4 ft. 6 in. by 3 ft., and the cost per foot varies from 15*s.* to 1*l.* 5*s.*, *according to the depth*. One of the sewers, from Hoxton New Town, is laid, for a length of 3000 ft., on a dead level, and discharges into another, which is also on nearly a dead level, because a fall could not be obtained. From the

45 miles of sewers in this division, about 2000 loads of sewage have to be annually removed by hand. All the outlets are into the Thames, below London Bridge, and are provided with valves, which sometimes fail, owing to some matter issuing from the sewers that prevents their closing, and of course the tide rushes in. Up to the year 1843, 13,000 ft. of sewers were rebuilt, at a lower level than formerly, in order to accommodate levels not then provided for, and at the same time maintain the communication with the river.

206. In the Surrey and Kent division, all the main arched sewers are necessarily provided with flaps and penstocks, nearly all the district being below the level of high water in the river. Some of the sewers in this division have only 2 ft. of fall per mile.

207. In the Holborn and Finsbury division, 38,000*l.* were expended upon the Fleet sewer between the years 1826 and 1843, and the surveyors were enabled to reduce the size of a part of it from 12 ft. by 12 ft. to 10 ft. by 9 ft., "from an advantage in the difference in the fall, there being more fall in this situation, which rendered the proportion of the current through the smaller sewer equal to the larger one." The extra expense incurred by the increased depth, which sometimes occasions a passing through sand and treacherous materials, may be inferred from one item in the cost of construction, viz., that in such cases it is found necessary to use close timbering to strut the sides of the excavation; the sand will also sometimes, despite all precautions, rise 6 inches in one night; and the building of some of the sewers in Pentonville "had the effect of loosening the ground, or causing the ground to slip, the whole way up the hill," and thus seriously damaging the walls of the gardens above. The Fleet sewer, as already de-

scribed, takes the water from Highgate and Hampstead, conducting it towards the river Thames, and it has been known "to rise six, eight, and ten feet in a night; there have been instances of persons being carried away by it." The fall in that part of it which is 12 ft. by 12 ft. is at the rate of a quarter of an inch in 12 feet; and in the 10 ft. by 9 ft., the fall is three-quarters of an inch in 10 ft. The effect of this difference of declivity is, that "if the 12 by 12 were completely full, the other would not be full by 2 ft."

The following extracts from the evidence given by Mr. Roe, surveyor to the late Holborn and Finsbury commission of sewers, before the Commissioners of Inquiry into the state of large towns and populous districts, in 1843, will give some notion of the state of the sewage of that division. "The Holborn and Finsbury divisions are peculiarly situated, having no immediate communication with the river Thames. The waters from these divisions have to pass through one or other of the adjoining districts, namely, the city of London, the Tower Hamlets, or the city of Westminster, before reaching the river. The sewers of the Holborn and Finsbury divisions have, therefore, of necessity, been adapted to such outlets as the other districts respectively afforded; and these having formerly been put in without due regard to an extended drainage, the sewers of these divisions have not had the benefit of the best fall that could have been obtained. Of late years many of the outlets have been lowered in the adjoining districts; but to alter the existing sewers of these divisions to the amended levels would require the rebuilding of about 323,766 ft. of sewer, at an expense of nearly a quarter of million sterling." In this state of things, Mr. Roe conceived that the ordinary current of water

which passes along the covered sewers (in some constant, in others periodical), in these divisions, which, in numerous cases, does not prevent deposit from accumulating, might yet be made available for that purpose; and accordingly "a series of experiments were commenced, in order to ascertain what velocity could be obtained in the sewers; and it appeared that deposit might be removed by the means of dams placed in certain situations to collect heads of water, at less expense than by the usual method. Another series of experiments were made for the purpose of endeavouring to ascertain the proportion of decomposed animal and vegetable matter, and detritus from the roads, carried through the sewers to the river Thames by the common run of water. Several square boxes were constructed, to hold 1 cubic foot of water each. These were filled with water from different sewers. After allowing the turbid water to clear itself by precipitation, I ascertained the relative amount of the precipitate. The following were some of the results:—From the river Fleet sewer, near the outlet, the proportion of decomposed animal and vegetable matter, and detritus from streets and roads, held in mechanical suspension, was 1 in 96. The run of water was 10 in. in depth, and 10 ft. in width, having an average velocity of 83·47 ft. per minute, passing 692·8 cubic feet of water per minute; the matter conveyed being 7·21 cubic feet per minute, or 103·660 cubic yards per annum. The river Fleet sewer conveys the drainage of about 4444 acres of surface, or about four-sevenths of the surface of these divisions. That great quantities, in addition to the above, are carried away by the force of water in rainy weather is certain; allowing this source, and the *remaining three*-sevenths of the district to only equal

the discharge by the river-Fleet sewer, there appears to be a quantity of upwards of 200,000 cubic yards of matter carried to the Thames per annum from these divisions in mechanical suspension, and by the force of velocity, weight, and volume of water." In one part of this division (at Canonbury) the sewer is *sixty-eight feet below the surface*, and *the drainage of the houses is provided for by a subsidiary sewer.*

208. In the Westminster division the outfalls to the river vary from 10 to 15 ft. below the level of high-water mark, that is about 5 ft. above low-water mark, and some of them are provided with flaps. The cost for cleansing sewers by hand, made necessary by deficient fall, amounted in the year 1842, to 1850*l.*; the average for seven years, being about 1,550*l.*, and this deposit is so hard that it is sometimes found necessary to use the pick-axe to dislodge it. Some of the main sewers have a fall of only ½ inch in 100 ft. During the ten years ending 1843, 27,056 yards of sewers were constructed by the Commissioners for this division, and these were principally old sewers *built at a lower level,* or diverted along the public way. The size of the main sewers is 3 ft. in width, and 5 ft. 6 in. in height, and of this size 32,000 yards were constructed from 1833 to 1843 jointly by the Commission and by individuals. In 1843 one of the sewers in this division, the King's Scholars' Pond Sewer, was described to have from its commencement at Shepherd's Well to the flood gates at the Thames a total fall of 285 ft. 4 in., yet the fall is in some parts very deficient. In the Pimlico district adjoining the palace, the fall is for the last 5500 ft. only 5 ft.;—less than a foot in each thousand feet, and the outlet was still so low that flood gates were necessary at its outlet. During the rising of the tide, therefore,

these gates were closed for six hours, and the sewage of course remained pent up or thrown back towards the houses.

209. In the Kent and Surrey divisions, in which there are several open sewers, the drainage is so conducted that "during the time the tide is up in the river, the sewers have to receive all the water, making its way into them, and must be sufficiently capacious to hold both that quantity, and all rain that may fall, until the fall of the tide allows a discharge." The covered main sewers are 5 ft. 3 in., by 4 ft. 9 in. The whole of the district is many feet under high-water mark.

210. The facts here quoted are certainly sufficient to show that the system of draining into the Thames is attended with vast extra expense in the depth and size of sewers, and with great inconvenience and inefficiency in the want of declivity thereby laboured under, which are powerful considerations against the propriety of this method, and the weight of which has to be added to that of the loss occasioned by the utter waste of most valuable manuring matters, and the injurious effects of saturating these matters in the water from which the daily supplies for the metropolis are mainly derived.

SECTION II.

Supply of Water.—Public Filters and Reservoirs, &c.

211. *Quantity* and *quality*—criteria of every-day plication—have special reference to the supply of water

for every congregation or community of human beings. The varied practical purposes of domestic life to which this invaluable agent is alone applicable, and the intimate connection of many of these purposes with the health, life, and well being of humanity, at once attest the high importance of abundance and of excellence in our command of water. Rivers, springs, and surface collections have already been enumerated as the several sources of water for the use of towns and the advisability of resorting to one or other, or combinations of these sources, has been shown to have some dependence upon the superficial contour of the town and suburbs. Facility of supply, promoting the economy of the means, will of course always have great influence in determining the source to be referred to. Rivers and their feeders—brooks or streams—may be classed, as the most abundant sources in most instances, but their applicability can seldom be realized without some expenditure of power—natural or artificial. Surface collections and springs, on the other hand, are frequently applicable by the force of gravity unaided by power, and requiring only suitable channels in which the supply may be conducted from the higher lands around the town. The cost of power has, however, lost much of its importance as an element in the calculation since the steam engine has enabled us to perform constant and easily regulated duty in the raising and conveyance of water at a very small expense; and, therefore, the comparative abundance of the several sources at all seasons will determine the preference rather than the susceptibility of self-propulsion.

212. Where a choice is afforded as to sufficiency of supply, however, the *qualities* of the water should be allowed great influence in ruling the selection. Tracing

all these forms of immediate supply to the common original one of rain water, we may readily infer from a knowledge of its ordinary properties, and of the effect of its subsequent treatment, the particular stage of this treatment at which it will be the most desirable to convert the water to our purposes. Rain water, as already shown (Part I, paragraph 30), contains ammonia, but it is, as well known, the least impure in constitution of any water at our command. All the earthy, animal, and vegetable matters with which water becomes charged, are extracted from the soil through which, or the surfaces over which it passes. The nature of these matters depends upon the constituents of the soil which is percolated, the amount of them will be in proportion to the time during which the water is maintained in communication with the soil, modified of course by the degree in which they may be adapted for mutual action. Hence it follows that the scale of comparative purity would stand thus:—1. Rain-water. 2. Water from surface drainage. 3. Water from soil drainage or percolation. 4. Water from rivers or brooks. 5. Water from springs and subterranean sources. Regarding No. 4, however, it is to be remarked that the collection of the water in any kind of channel allows of a partial deposition of the heavier particles which the water has imbibed, facilitated of course by the depth of the body of water, and the slowness of the current, or minimum of motion. And besides this, the exposure of water to the action of the atmosphere appears to assist the evolution of some constituents which impair its purity. Water from streams and rivers comes thus to be considered as next in comparative purity to rain water immediately derived, while that taken from springs and *sources in which* it has long remained in intimate con-

tact with soluble earths and other matters, is found to have acquired a corresponding proportion of these impurities.

213. The different kinds of impurities contained in water have been explained (32 and 33), and the means of testing and correcting some of those shown (34 and 35). The process of filtration through the soil, which the water derived from subterranean sources undergoes, tends to separate the animal and vegetable impurities, and thus spring water and well water being comparatively clear, are commonly reckoned as pure. The matters which these waters nevertheless contain are, however, separable only by chemical treatment, while the impurities of river water may be got rid of to a great extent by mere subsidence and self-filtering.

214. The several purposes for which water is required in a town, or collection of people, are—1. Ordinary domestic uses, including drinking, washing of persons, clothes, utensils, houses, yards, and watering gardens, &c. 2. Manufactures. 3. Supply of public buildings, baths, wash-houses, &c. 4. Extinction of fires. 5. Cleansing and watering of streets and thoroughfares. 6. Supply of fountains, and public gardens, and pleasure grounds. 7. Miscellaneous and occasional purposes not included in the foregoing.

215. The supply necessary for the total of these purposes may be reduced into an average quantity for each individual of the population, and each square acre, yard, or foot of the superficial area of the town. The latter datum will also afford the means of estimating the proportion of the supply which will be immediately rendered in the form of rain, and the difference between the amount of which, and the total quantity required,

will represent the proportion to be served by other means.

216. Adopting 24 inches as the average annual fall of rain, and half of this as remaining after evaporation, as this quantity will facilitate an approximate calculation, and be sufficiently near the truth for the purpose, (an exact average for places, years, and seasons being scarcely calculable even by the most laborious computation,) it appears that 1 cubic foot of rain water is annually retained upon each square foot of surface, or 9 cubic feet on each square yard, equal to 43,560 cubic feet upon each square acre.

217. For the first, second, third, and fourth of the purposes enumerated (214) a daily supply of 20 gallons for each individual will be a fair average, being more than sufficient in towns having an ordinary proportion of manufacturing operations carried on within them, and nearly, if not quite so, even in towns where an excessive proportion of manufactories exist. This may be inferred from the quantities now supplied in towns. In Preston, Lancashire, the supply by the Waterworks Company is on an average 80 gallons daily to each house, including factories and public establishments, and as the service is constant and the quantity unrestricted, it is presumable that much of this quantity is wasted, and, if properly reserved, might be made to supply, partially at least, the cleansing of the streets. The tenements occupied by the labouring classes in this town are estimated to consume only 45 gallons each daily. Assuming 5 as the average number of occupants of each house, the supply to each in these cases will be 16 and 9 gallons respectively. In Ashton-under-Lyne the daily supply to each house is 55 gallons, or 10 gallons

to each person; and 18 factories in this town consume 1,103,000 gallons daily. Experiments tried in the year 1847 proved that the daily consumption per head of the tenants supplied by the Ashton Waterworks Company averaged 6·245 gallons; while the quantity supplied to the mills in the neighbourhood averaged about 7 gallons per head in addition, making a total of about 14 gallons per head per diem. In Nottingham, the "Trent Water Company" supply 17 or 18 gallons per individual, daily, including the trade consumption. The quantities supplied by four of the leading companies in the metropolis are as follows:—

East London	100	gallons	per house	per diem.
New River	114	,,	,,	,,
West Middlesex	150	,,	,,	,,
Chelsea	154	,,	,,	,,

These rates of supply will be found to corroborate the average we have assumed for each individual. Thus in the district supplied by the East London Water Company, including Spitalfields, Bethnal Green, Poplar, Limehouse, and other populous neighbourhoods filled with the poorer class of persons, it will be found the average number of persons is much above 5; 7 or 8 would probably be much nearer the truth. The New River Company also supplies populous districts. Many of their customers are similar to those just described, and the average of all would certainly give more than 5 persons to each house. In the districts supplied by the West Middlesex and Chelsea Companies, the population is mainly of another class, or rather classes, but all of which occupy larger houses than those in the Eastern and Northern parishes, and the average con-

sumption in each house is high in comparison with the others, owing to two causes, the larger number of residents in each house, including domestics, &c., and the larger quantity consumed in baths and other means of private luxury and comfort which are beyond the command of the other classes of society.

218. Although it would thus appear that an allowance of 20 gallons per diem for each head of the population will suffice for domestic and manufacturing purposes, including the supply of public buildings and for the extinction of fires, we would prefer to provide for a constant service of 30 gallons, in order to make an ample provision for all possible casualties and increased demands. Water is pre-eminently so valuable, and, when properly sought, so cheap an agent, that extravagance should always be permitted rather than a deficiency be risked.

219. For the three remaining purposes, viz.;—the cleansing and watering of streets and thoroughfares, the supply of fountains and public gardens and pleasure-grounds, and such miscellaneous and occasional purposes as are not included in the six preceding classes, the average quantity of water required may be reduced, for an approximate estimate, into a given depth per diem, or annually, according to the surface occupied by the town and suburbs to be supplied. Towards this quantity, the rain may, as we have seen (216), be estimated to contribute an annual average depth of 12 in. available water. Now, allowing $\frac{1}{10}$th of an inch of depth of water to be daily required over the entire surface of the town for the several purposes stated, and we believe this to be a liberal allowance, we shall have an annual total depth of $365 \div 10 = 36{\cdot}5$ in. which *may be regarded* as 36 in., from which, deducting

the 12 in. supplied by the fall of rain, we have the remainder equal to 24 in. depth to be supplied by other means.

220. We thus derive a rule as to the quantity of water required to be supplied in any town, which calculates the total quantity upon two given data, viz.:— First, the amount of the population; and, secondly, the superficial extent of the town and neighbourhood to be provided for. Thus, by way of example, let us suppose a town having a population of 100,000 persons, and an area of 1000 acres. The quantity required to be provided annually for this town, would be,

	Gallons.
Population 100,000 + 30 + 365 =	1,095,000,000
Area 1000 + 43,560 + 2 + 6 =	522,720,000
Total annual quantity	1,617,720,000

allowing each cubic foot to equal 6 imperial gallons, which is sufficiently near the truth for a general calculation.

221. Having thus endeavoured to arrive at an approximate estimate of the *quantity* of water required for any town, formed upon the data of the amount of population and extent of surface to be supplied, we have now to refer to the question of *quality*, and cite such observations as we can, which have tended to exhibit the qualities of water derived from the several sources of rivers, springs, and surface collections, or superficial drainage. In these particulars it will also be useful to include such accounts of the topographical and geological features of the towns and districts referred to as we can collect from the trustworthy testimony of witnesses before Public Commissioners.

222. The borough of Preston comprises an area of 1960 acres, a population (in 1841) of 50,131, and 9994 houses at the same date. The town stands principally upon a dry sand of the "recent formation," marl, clay, and gravel existing in some parts. At a depth of about 90 ft. from this surface-soil, the "new red sandstone" is found; the same rock forming the bed of the river Ribble, which through 2 miles of its course flows at about a quarter of a mile distance from the town, which has a general westerly slope towards the river, the highest sites being about 130 ft., and the lowest about 35 ft. above its low-water level. More than half of the town is supplied with water by the Preston Waterworks Company, which derives its supply from the "mill-stone grit" formation at Longridge, distant about 7 miles eastward from Preston. The remainder of the town is supplied from wells. The whole of the supply from both sources is described as of excellent quality, but we have no analysis to determine its ingredients. The geological influences to which water derived from such strata as are here described are certainly likely to furnish a water of good general quality and comparatively free from soluble mineral impurities, while the elevated position of the town in relation to the river would discourage a resort to it for general supply upon economical grounds.

223. Chorlton-upon-Medlock, one of the townships of the borough of Manchester, from which it is indeed separated only by the little river, Medlock, comprises an area of about 700 acres. The number of houses in 1841 was 6021, and the population about 29,000. The soil is of two kinds, stiff clay over the southern part of the town, and gravel chiefly over the northern. *The geological* formation is the new red sand-stone,

which is found at depths varying from 3 to 90 ft. from the surface. A stream called "Corn Brook" which flows through the township for more than a mile, and delivers into the river Irwell at a distance of about two miles, is little better than an open drain, and keeps that part of the town near to its banks in a damp and unhealthy condition. The supply of water is derived partly by a Waterworks Company from Gorton Brook, which affords the only stream-water fit for use, and partly by pumps from wells in the gravel and sand-stone. The water from these latter sources is described as being "bright and sparkling and well tasted, but hard."

224. The town of Ashton-under-Lyne is built on a gentle declivity on the north-west bank of the river Tame, above which it is elevated from 30 to 40 ft., the surrounding country being remarkable for its generally level character. The principal geological feature of the neighbourhood is the great coal deposit, the surface-soil being clay and loam, and the subsoil clay and gravel. The sub-strata are chiefly schistus and sandstone, with intermediate layers of coal. The water for the supply of the town is derived by a Waterworks Company from springs in the higher parts of the parish, and is of a medium quality, being such, however, that it is said to be "wonderfully" improved by filtration.

225. York, situated in the centre of an extended vale, lies between the rivers Ouse and Foss, and immediately above their junction. Both of these are navigable and tidal rivers, but the tide is prevented from rising to the city by a lock placed five miles below it. The available water is derived from the river Ouse, from wells varying in depth from 12 to 40 ft., and from borings from 350 to 380 feet deep from the surface.

The inquiries of the Rev. W. Vernon Harcourt, and of Messrs. Spence and White, of York, have furnished us with much valuable and accurate information as to the qualities of these waters, and the geological conditions in which they are presented; and, from the records of these inquiries, a few facts may be advantageously quoted as illustrations of general principles, which will be found commonly applicable to the several sources of water for the supply of towns.

226. From these records it appears that the total of *gases* contained in one gallon of river water, from the Ouse, amounted to 10·4 cubic in., and the average of 14 waters from the springs, or superficial wells, amounted to 23·8 cubic in. That the total of solid contents, (consisting of carbonates of lime, magnesia, and iron, sulphates of lime and magnesia, muriates of soda and potash, silica, and vegetable matter,) in one gallon of river-water amounted to 9 grains,—while the average solid contents of the 14 well-waters amounted to 64·96 grains per gallon, comprising the same carbonates, sulphates, and muriates as found in the river-water, with the addition of muriate of lime in some specimens, and of the nitrates of lime, soda, or magnesia in all. An analysis of the water from the deep springs, made by the Rev. W. V. Harcourt, showed the presence of 96 grains of solid contents in one gallon, and of this quantity about half consisted of medicinal salts; viz., 33·9 grains of the crystals of sulphate of magnesia, and 14·4 grains of the crystals of sulphate of soda, besides a small proportion of bicarbonate of iron.

227. The causes of these differences of ingredients (which, together with considerable difference of level *at which* the waters are maintained in the several wells,

evince their independence of each other, and of the river,) are referable to the geological conditions under which they are collected. The section of an Artesian well sunk to a depth of 378 ft. in the city showed the following arrangement of strata:—clay and gravel, 18 ft.; fine river-sand, 60 ft.; sandstone rock and loose sand, 60 ft.; a thin seam of blue clay and water, and sandstone rock, 62 ft.; another thin seam of clay and water, and sandstone rock, 178 ft. The Rev. W. V. Harcourt describes this sandstone formation, and the structure of the bed of the river Ouse, as follows:—"This sandstone rock belongs to the beds of the new *red sandstone* formation, which crop out in a low line of undulating hills along the western margin of the basin of the vale of York, passing in a south-easterly direction from Rainton to Borough Bridge, and Ouseburn to Green Hammerton, and emerging again from beneath the diluvial covering of that basin at Bilbrough, within a few miles of York. The immediate substratum of the soil in this line over a considerable tract of country consists of these porous beds, and the water which falls or flows down upon it passes through them, between the seams of clay which alternate with the sandstone, along the dip of the strata, eastward to York; it is thus carried between the diluvium below the bed of the Ouse, and is dammed up under the superincumbent mass, in the reservoirs of the sandy beds, to the above-mentioned height of 15 or 20 ft. above the summer level of the river, to which height it is found to rise where the superior seams of clay are perforated by boring. The water of the Ouse consists chiefly of the contributions of the rivers which flow from the high hills on the north-west of York, (especially the Swale, the Ure, and the Nid,) and are fed by the rains

falling on their summits. The streams from this source, after percolating the *mill-stone grit*, with which those hills are capped, find their channels on the surface of the impervious beds of the subjacent *limestone* and *shale* along the valleys, and are conveyed on linings of *diluvial clay* across the edge of the superior strata, and over the drift-covered plan of the *red sandstone* to York. To this account of the geological conditions under which York is supplied with water, it is to be added:—1st. That the gritstone hills which furnish the river-water include few materials of saline impregnation. 2nd. That the beds of the red sandstone in which the deep springs run are pre-eminently saliferous. 3rd. That the rubbish of centuries accumulated in some parts of the city to the depth of three or four yards over the diluvial beds, which contain the superficial wells, is full of decomposing matters, tending to mineralize and contaminate the water. The waters of these wells, accordingly, are highly charged with solid matters, amounting, on an average, to about 60 grains held in solution in an imperial gallon. In two cases Mr. Spence found in them from 6 to 7 grains of Epsom salts, and in one 11 grains; in two others he found 31 and 38 grains of neutral salts of soda and potash. In these last an infiltration may be suspected from the deep springs; but in general there are sufficient materials in and upon the drifted beds to account for the sulphate and carbonate of lime, of which the solid contents of these waters are chiefly compounded, and which render them harder than is desirable, either for drinking or for culinary use."

228. The evidence here so well adduced is amply sufficient to account for the differences observed in the chemical qualities and adulterations of the water derived from the several sources, while that from the

river, Ouse, on the other hand, furnished by the grit stone hills, being purer at its source, and subsequently improved by exposure to the air, contains only 9 grains of solid contents in the gallon, and presents an exhaustless source of water of excellent qualities for all the purposes of the city.

229. The materials of some soils are peculiarly prejudicial in their effects upon water passing through them. Thus peat impregnates the water passing through it to so great an extent, that it becomes discoloured, and thus exposes the origin of its impurity. Mr. Homersham, who devoted much attention professionally to the several water-sources around Manchester, has recorded his observations on this subject, and cites the confirmatory remarks of persons residing in the valley of Longdendale in that locality, that "upon heavy rains following a drought in the summer time, the water flowing down the streams is about the colour of London porter, and so strongly impregnated with moss and peat, 'that it can at such times be smelled a field off.'"* When the water derived from peat lands passes through mineral rocks of particular formation, a process of natural filtration is effected by which the colouring matter is absorbed, and the water emerges in a tolerably pure state. This fact was observed by Mr. Thom in examining water which flowed over or through a particular species of lava or trap-rock (amalgoiloid) in the hills above Greenock, and was found to have thus become purified equal to fine spring water. Mr. Thom made good use of this observation by substituting this rock, obtained in that neighbourhood at a no-

* "Report on the Water that can be Supplied to the Inhabitants of Manchester and Salford. p. 85." Weale, 1848.

minal price, for charcoal in the subsequent process of artificial filtering.

230. The town of Nottingham, which is chiefly at a considerable elevation above the surrounding country, on the southern, eastern, and western sides, occupies the declivity of the southern termination of a long range of hills, and has the valley of the Trent about one mile in width at its foot. Three-fourths of the town has an elevation from 50 to 200 ft. above the valley, and stands immediately on the new red sandstone rock, which, being absorbent, remains dry on the surface. The remaining portion of the town has a substratum of similar material, but stands immediately on an alluvial deposit of gravel silt, and decayed vegetable matter, lying in the valley of the Trent or its tributary streams. By two of these, the Leen on the south, and the Beck on the east, which flows into the Leen, the waters are conveyed into the Trent. The town is supplied mainly by two water companies, whereof one derives its supply from springs, situated about 1½ mile north of the town; and the other from the river Trent, on the banks of which a reservoir and other works have been constructed. A small part of the population is supplied by minor works, which by means of steam engines raise their supply from wells sunk in the new red sandstone rock. The quality of all these waters is described as being good, but those from the sandstone contain "carbonate of magnesia in notable quantity," besides the sulphate and carbonate of lime, muriate of soda, &c. It is quite certain, therefore, that this water is for all ordinary purposes impaired in its purity and value.

231. Liverpool is situated partly on the side of the *ridge of hills* forming part of Everton, Edge-hill, &c.,

and partly on the crest of a minor elevation, the valley between the two having been the original streamlet or channel, which discharged into the old pool. The substrata of about two-fifths of the city of Liverpool is clay. Along the banks of the intermediate valley the soil is chiefly a deposit of mud with occasional beds of gravel, and in some parts irregular masses of rock. Between this valley and the southern and eastern boundaries of the town, a mixture of yellow sand and rock is found in small thin beds, but generally resting upon solid rock at an average depth of 15 ft. Liverpool is supplied with water by two public companies, one of which derives its supply from springs at Bootle, distant 3 miles from the town, and the other from wells in various parts of the town. These waters were analysed by Dr. Trail in 1825, and found to contain "muriate of soda and of lime, the last in very small quantity; sulphate of soda, and possibly a minute quantity of sulphate of lime, carbonate of soda."

232. The town of Bilston has a declivity towards the brook called Bilston Brook at its base, the fall being steep in the upper part of the town, and gentle in the lower part. "The geological character of the country is that of the coal measures overlying the Wenlock limestone. The only peculiarity is the presence of porphyritic greenstone, and occasionally compact basalt. The soil of Bilston, where collieries have not been opened, has a preponderance of aluminous earth. The subsoil is generally brick earth. The sandstone is rather an important feature in the geology of Bilston, on account of its compactness and great thickness." The water for the town is chiefly supplied by a Waterworks Company, and being collected by land-streams which flow over beds of limestone becomes impregnated with

lime, and thus acquires a considerable amount of har(ness.

233. Newcastle-under-Lyne stands partly on the o red sandstone formation, and partly on a strong mine clay which extends into the coal formation of the Pc tery district. The water springing from the form formation is somewhat hard, containing a small porti(of carbonate of lime. That from the clay is much mo hard, from its greater quantity of this carbonate.

234. Bath, which is built partly on the slope aı lower part of a hill, rising from the right bank of t river Avon, where it forms a considerable bend rouı from east and west to north and south, stands upon t nearly horizontal beds of clays, limestones, sands, a: sandstones which constitute a portion of the series rocks to which the term oolitic has been given from t oolite or oviform grains in many of the limeston(From the interstratification of these different kinds rocks conditions for the occurrence of springs a numerous, and they are accordingly often met wi and from these the town is supplied with water 1 domestic purposes. These springs occur at varic elevations above the height of the river Avon, from 1 to 160 ft. The qualities of the water raised from t several wells vary according to the beds of limeston clays, marls, sands, &c., in which they are formed. the alluvial ground, on the right bank of the river a lower parts of the town, trees are sometimes met w in great abundance. These lie beneath an alluvial ı loam, about 8 ft. thick, resting on gravel of about t same thickness, and this upon lias clay. The wa where these trees are found is abundant, but ne' good. Some of the wells in the lias furnish tolera water, but there are examples of sinkings in it to

depth of 200 ft. from which no water has been obtained. The sections of many wells sunk in the neighbourhood of Bath show that the water is retained among the various beds of clays at great depths beneath the Great and Inferior Oolites, and produces springs by cropping out on the sides of the hills.

235. While the topographical and geological character of the site of the town, and of the soil and substrata on which it stands, are the admitted guides as to the source or sources from which the town may be supplied with an adequate quantity of water of average goodness of quality, the criterion of quality as measured by relative *hardness* must be allowed a prevailing consideration. River waters, rendered impure chiefly by organic, animal, and vegetable matters, are susceptible of improvement by methods of filtration; whereas waters derived directly from drainage or internal springs are comparatively pure in these respects, but on the other hand are charged in infinite degrees with earthy and mineral matters which at once render them less fitted for domestic purposes, and far less readily susceptible of purification. The economical results of the qualities of the water supplied to towns have been adverted to at some length in the first Part of the Rudimentary Treatise on Drainage. (Paragraphs 33, 34, and 35.)

236. In concluding these remarks on the qualities of waters from various sources as subjects for consideration in estimating their comparative value, we may usefully refer to the confirmatory evidence supplied by analyses made under the direction of the Superintending Inspectors to the General Board of Health, of the waters available in the several towns of Chatham, Uxbridge, Croydon, and Dartford, reported upon by Mr. Ranger. The analyses were made by Dr. Lyon Playfair.

237. The water now used in Chatham is obtained principally from surface drainage from the upper chalk, but it varies greatly in the degrees of hardness. Adopting, as is presumed, the same measure of hardness as that used by Dr. Clark, and explained in Part I. (34), the hardness of the surface water from nine places of collection varied from 17° to 56°, the average of the nine being 27°, while the water of the River Medway has only 5½° of hardness. This water, however, contains a large quantity of a yellow deposit; and, comparing the qualities of all the waters, the Inspector recommends that the supply should be taken from the Boxley Abbey Spring, of which the hardness stands at 17°. This spring is about 5 miles from the town, and the situation being backed by elevated ground and considerably higher than any part to be supplied, is peculiarly adapted for the construction of reservoirs and filtering beds if required. The Report leads us to suppose that the reasons for preferring to bring water a distance of 5 miles, while that from the river is accessible to all parts of the town, is to avoid the expense of artificial raising of the latter. The relative hardness is, however, an item of great moment, and should receive full consideration. The deposit remarked in the river water occurs, there is no doubt, from earthy matters held partly in solution, which would be readily removable by filtering.

238. Uxbridge is now supplied with water from four public pumps, from wells, and by dipping from the branch of the river Colne. The hardness of the water from three town pumps and two others varied from 26° to 52°, the average being nearly 36°. The hardness of the water from one of the Artesian wells was found to be 34°; of that from two others 14½° and 16° re-

spectively. From the small degree of hardness in these two latter waters, we might conjecture some communication between these wells and the river Colne, the water of which has 15¾°, but the Report does not remark on this circumstance. The Inspector advises that the adequate supply for the town should be derived from the river Colne, at a part which will be favourable for the construction of reservoirs, filtering beds, and other necessary works.

239. The waters now supplied to the town of Croydon from springs and wells are found to have an average hardness of 25¼°. That from the river Wandle has 16°·1, and Dr. Clark reports that an expenditure of 1 lb. of burnt lime will, by his "lime-water softening process," suffice to purify 800 gallons of this water, reduce its hardness to 3°·9, and effect a saving of curd soap required to form a lather with 100 gallons of the water, of 24¼ oz. The Inspector recommends the river Wandle as the most eligible source, from its contiguity to the town, the favourable quality of its water, and its sufficiency to afford the means for a supply upon the constant system.

240. The town of Dartford is now supplied by wells and pumps and dipping from the river Darent. The water from seven of these sources, excluding the river, has an average hardness of nearly 18°, while that from the river has only 13½°, and is recommended by the Inspector as being the most desirable for the supply of the town.

241. The third consideration affecting the supply of water for towns is the relative expense at which this supply can be obtained. Springs and other sources of the less pure waters, are, doubtless, usually of more ready and economical adaptation than rivers. Upland

streams and watercourses are generally applicable to some extent for supplying the adjacent parts of the town and suburbs, but the higher elevations frequently involve extra cost in forcing water from these lower sources. With a great scarcity of records of the cost of works and conducting of the existing arrangements for supplying water to towns, we are driven to form estimates which can only be assumed as approximate, but will nevertheless suffice probably to indicate the relative economy of the several methods of supply which may be adopted.

242. The main items of cost of the supply of water to towns are:—1, collecting; 2, storing; 3, filtering; and, 4, conveying. If the supply be derived from surface-drainage or springs at superior level, so that no raising is required, the first of these items will comprise the construction of open channels, aqueducts, or artificial rivers with tributary or catch-water drains where necessary. If the supply be derived from a river or other source at lower level, this item for collection must be understood to include the expense of raising the water and delivering it to the storing or filtering beds with such constructions of channels or piping as may be necessary for that purpose. The storing places or impounding reservoirs for drainage waters are sometime so constructed as to answer also the purpose of filtration, and thus combine in one cost the items Nos. 2 and 3.

243. Mr. Robert Thom, who has successfully supplied several towns with water collected from surface-drainage and natural collections or basins, considers it desirable that the reservoirs should be large enough to hold at least four months' supply of water, this being *necessary* to provide against the irregularities of supply

of water obtained from these and similar sources. For the storing of water taken directly from rivers and other ample sources from which an abundant quantity can at all times be commanded, reservoirs of less capacity are sufficient, and the first cost of construction is therefore reduced. The catch-water drains, in which the water is first received, are made to communicate either directly with the main reservoirs, or by the medium of aqueducts. From the main reservoir the water is conveyed by another channel or aqueduct into other reservoirs or regulating basins near to the town, and each of them so situated in elevation that the water from them shall rise above the highest desired service, and of such capacity that each will contain enough for two entire days' supply of water for the town.

244. If the water cannot be delivered into the regulating basins at sufficient elevation, artificial power will of course be required to raise it from the natural to the desired height. From the regulating basins it is delivered into two or more self-cleansing filters (as before described, Part I. paragraph 48), and from these into two distributing basins, whence the water is carried through the streets by a system of piping. Thus the town appliances are provided in duplicate, and the object of this is to enable one set of apparatus to be constantly commanded, and each to be alternately cleansed or repaired when necessary.

245. In our fifth Section of this Division we shall have to enter into the details of apparatus for conveying and distributing water. Our present purpose is to enumerate the general varieties of arrangements required according to the source from which the supply is derived.

246. The increased expense incurred in the formation

of large reservoirs to hold a supply for a long period, such as four months, is certainly great, but not so when compared with the first cost of machinery and current expenses of raising water from rivers and sources of low elevation. The upper sources of springs and drainage-waters are, moreover, applicable in some cases where the others are inaccessible, or rendered so practically by the great distance and low elevation from which river-water can alone be conveyed and raised. The cost of constructing reservoirs may be estimated at about three-pence per cube yard on an average, if no extraordinary difficulties or expensive works are required. With reference to reservoirs as proportioned in capacity to the number of houses or persons supplied, the following particulars may be usefully cited referring to the operations in seven of the large towns in Lancashire, and reported upon by Dr. Lyon Playfair:—

Towns.	Number of Houses in Town in 1841.	Number of Houses or Tenants Supplied.	Capacity of Reservoir in Gallons.	Height of Surface of Water in Reservoirs above.	
				Highest Parts of Town.	Lowest Parts of Town.
				Feet.	Feet.
Manchester .	57,238	30,000	2,000,000	0	155
Salford . . .			249,360,000	0	122
Preston	9,984	5,026	50,000,000	36	160
Bury	5,260	2,980	4,181,760	50	130
Ashton	4,700	4,000	100,000,000	200	260
Rochdale . . .	8,266	2,800	22,781,253	6	96
Oldham	8,220	5,620	85,000,000	30	300

The capacity and expense of reservoirs for drainage or surface-collected water will of course be regulated with a view not only to the wants of the population, on the one *hand, but* also with reference to the extent of surface to

be drained, and probable quantity which will thus accumulate. From some statements given in the Report by Mr. Homersham, before quoted from, we may present the following figures:—

Names and Situation of Reservoirs.	Contents of Reservoirs.	Area of Drainage Ground.	Per Acre of Area.
	Cubic feet.	Acres.	Cubic feet.
Turton and Entwistle Reservoir, 14 miles N.W. of Manchester . .	100,000,000	2036	49,110
Belmont Reservoir, 14 miles N.W. of Manchester	78,000,000	1796	43,430
Bolton Waterworks Reservoir, 4 miles W. of Bolton	22,471,910	595	37,767
Ashton Waterworks Reservoir, 1½ miles N.E. of Ashton	14,436,397	378	38,453
Sheffield Waterworks— Redmires Reservoir	30,000,000	912	32,894
New do. do.	22,000,000		Total. 57,050

The aqueducts for passing a supply of 20 gallons per diem for each individual of a population of 500,000 may be estimated at from 400*l.* to 600*l.* per mile, according to the ruggedness of the ground and other items of expense. The cost of filters upon the self-cleansing principle will average from 6000*l.* to 8000*l.* to supply the same quantity. That constructed by Mr. Thom at Paisley, which produces regularly every 24 hours a quantity equal to 106,632 cubic feet of pure water, cost about 600*l.*, and he estimates that the expense of a filter "to give a supply of water of the best quality *for family purposes,* to a town of 50,000 inhabitants, may be safely taken at 800*l.*" This supply, however, allows only 13 gallons to each individual. We prefer allowing a minimum of 20 gallons as already estimated. (217.) Adopting the facts stated by Mr. Thom, as

experienced in supplying four towns in Scotland, viz.: Greenock, Paisley, Ayr, and Campbelltown, which are served by his system, but allowing the greater quantity stated, to each individual, and assuming the cost to increase in the same proportion, we find that the average annual expense per person will amount to no more than eight-pence, that is, for a regular daily supply of 20 gallons of good spring water throughout the year. This expense includes wear and tear of apparatus, charge for superintendence, &c., and 5 per cent. per annum upon the capital employed. In the towns here referred to there is such declivity that allows of high reservoirs and constant high service to the buildings without any expenditure for power. Mr. Thom states that the cost for apparatus for the smallest of these towns, Campbelltown, of 7000 inhabitants, amounted to about 2500*l.*; or say 3800*l.*, being about 10·85 shillings to provide for the daily allowance per individual of 20 gallons instead of 13 gallons.

247. At Nottingham, about 8000 houses, or 35,000 inhabitants, are supplied with water raised from the river Trent by a Waterworks Company. The actual supply is found to amount daily to between 80 and 90 gallons per house on an average, including breweries, dye-works, steam-engines, inns, and other places of large consumption. The levels of different parts of the town vary, perhaps, 80 ft., and the water pumped up from the river is raised above the town, so that an average pressure of 80 ft. is maintained, the greatest pressure being about 120 ft. The water is drawn from the river into a reservoir formed on its banks, and excavated in a stratum of clean gravel and sand, through which the water percolates to a distance of 150 ft. from the river. Besides the filtration which thus naturally occurs, the

water is still further clarified by passing through a tunnel 4 ft. in diameter, which is laid through a similar stratum for a considerable distance up the adjacent lands, and constructed of bricks, without mortar or cement. The expenditure for the supply of these 8000 houses amounts to about 30,000*l.*, and the average annual charge per house is about 7*s.* 6*d.*, the water being supplied at any level required, even into the attics of 4 or 5 story buildings. The average daily allowance to each individual supplied is here equal to about 20 gallons; and reducing the total expenditure and the annual charge per house to an original cost and current expense per individual, as we have done in reference to the four towns supplied by reservoirs and aqueducts from surface collections and higher springs, we shall find the two items stand thus:—original cost per individual, 17·14 shillings; current expense per individual per annum, including per centage on capital, &c., 1*s.* 8*d.* The comparative statement for the four Scotch towns and for Nottingham will, therefore, be this per head of the population supplied:—

	Original cost of apparatus, &c.	Current annual expense.
	s.	*d.*
Scotch towns supplied with *drainage* and *spring-water*	10·85	8
Nottingham supplied with *river-water* .	17·14	20

The qualities of the waters, their comparative hardness, &c. should be fully known and duly estimated as items in the relative economy of the two sources.

248. For the supply of some towns it will be found desirable to combine the two sources, namely, a river—and springs, or perhaps upper streams which, flowing from lands much higher than the general level of the river, preserve a greater elevation, and may thus be

applied to furnish the higher parts of the town effect a judicious economy of artificial power in ra the required quantity.

249. The expense of public filtering of water already been stated, Part I., p. 41 and 43, as vai from about 2000 to 9000 gallons per penny. An : age rate of 6000 gallons may be safely assumed a quantity which can be filtered at an expense of penny. The annual expense of filtering the suppl each individual of the population thus appears to : age only 1·2 penny. This calculation is quite co sive as to the superior economy of public over pr filtering, since no separate house apparatus for this pose can possibly be maintained in working ord this insignificant rate of expense.

250. The public filtering of water before distribu it into the mains and service pipes by which the st and buildings of a town are supplied, is, however, pably insufficient to secure purity in the water as by the inhabitants, if the quantity for each hous received and stored in a separate tank or cistern, w is seldom or never emptied or cleansed. In these ceptacles the minute impurities brought in with day's supply accumulate into a mass of growing foul stirred up by the daily delivery, and undergoing stant decomposition, and thus contaminating the e contents of the cistern and every pint of water w is drawn from it. This consideration, which ma confirmed by volumes of evidence, but is too pal to require proof, leads to the desirability of disper with these separate household accumulations of w by providing a constant supply in the mains and se pipes, so that any required quantity may be at all t *instantly* commanded. The supply rendered by

Trent Waterworks Company to the town of Nottingham and before referred to, is maintained upon this principle, the several advantages of which have been pointed out by the engineer to the works, Mr. Hawkesley, and since adopted as a general rule in the recommendations of the Superintending Inspectors to the General Board of Health.

251. The superiority of the constant service principle of the supply of water to towns over the occasional or intermittent principle is not greater in the comparative purity of the water thus obtained for the current use of the persons supplied than it is in the economy of the supply. The first cost of cisterns or tanks, with all the expensive and inefficient paraphernalia of cocks, waste-pipes, &c., &c., is entirely obviated by keeping the mains, service and communication pipes always charged. It is well known that the due care and cleansing of the house receptacles for water, whether tanks, cisterns, or butts, are greatly neglected, especially among those classes who are actively and incessantly engaged in their business or daily labours, and who are equally unable to command the services of others for such purposes. These receptacles are often imperfectly constructed and covered, open to the entrance of soot, dust, and dirt of all kinds, frequently exposed to the action of the sun, and neglected when repairs become indispensable. If these separate and inefficient means are superseded by keeping the water-pipes constantly charged, one large reservoir suffices for a whole town, or extended section of one, and this one reservoir may be so devised, constructed, and managed, that the combined supply shall be always maintained and delivered in the best possible condition. The economy of the system here advocated arises in many ways. The spaces occupied by the

house-tanks are saved, and the damp which always arises from the evaporation of bodies of water is avoided, besides preventing accidents, leakage, and the occasional inconvenience of finding the cistern empty, or its contents reduced to a few inches in depth of foul mud. Another source of economy is the reduction in the sizes of main and service-pipes required, as the delivery is distributed over a longer period than by the intermittent supply which limits the actual delivery for present and prospective purposes to a few hours, or some still shorter extent of time. Added to this diminution in the size of pipes permitted by the constant supply is the fact of their non-liability to be burst by the sudden gush of water which compresses the air within the pipes with a force which the strength even of iron cannot resist. The alternate absence and presence of water within them, moreover, hastens their corrosion, as it has been found that much oxide of iron accumulates in them under these circumstances. And beyond these advantages, the constant supply system possesses the further one of immense economy in management. It is found at Nottingham that one experienced man and one lad are sufficient to manage the distribution of the supply to about 8000 tenements, and keep all the distributory works, including cocks, main and service-pipes, &c., in perfect repair. Under the intermittent supply system, a numerous staff of assistants would be required to discharge similar duties.

252. The "Commisioners of Enquiry into the state of large Towns," have quoted a statement to the following effect:—That the expense of machinery or capital invested in the arrangements for supplying the metropolis with water, exclusive of the communication pipes to the *houses, the tenants'* water-butts, tanks, &c., amounts to

3,310,342*l.*, or about 3*l.* per individual supplied; that the annual income is 276,243*l.*, and the expenditure 133,724*l.*, leaving a balance which is equal to an average dividend of 4 per cent. The income from each individual supplied would thus appear to be somewhere about 5*s.* annually. Now, the metropolis is supplied mainly from the river Thames, the river Lea, and the New River, from a spring at Amwell. In the year 1843 the entire supply was furnished by nine companies, the names of which, and the sources of their water, were as follows:—

Companies.	Sources of Water.
Chelsea	River Thames.
West Middlesex . .	Do. do.
Grand Junction . .	Do. do.
Southwark	Do. do.
Lambeth	Do. do.
Vauxhall	Do. do.
East London . . .	River Lea.
New River . . .	Amwell and River Lea.
Hampstead . . .	Springs on Hampstead Hill.

The cost of construction for the water-supply at Nottingham, as already stated (paragraph 247) is between 17*s.* and 18*s.*, and the expense attendant on the supply of water and management of the works amounts to about 44 per cent. on the income, which will be found somewhat less than the proportion of the like expense in London. The expenses both of formation of works and of current supply are evidently controlled to a considerable extent by the natural facilities for the former, and by the distance from which the water has to be conveyed and the height necessary to raise it. The expense to individuals must of course be also liable to be affected by the proxi-

these soluble matters are found in spring and drainage waters in far larger proportion than in river-waters, which are more susceptible of being purified by a process of self-filtration, and are, therefore, commonly preferable for most purposes to waters of the former character. That the expense of raising river water by steam-pumping is really very small and unworthy of consideration, although often regarded as a weighty argument in favour of seeking the required supply from districts of land from which the water descends by gravity, without artificial aid.

And, *thirdly*, that the complete utility and greatest ultimate economy of the supply of water to towns can be realized only by a service of it which is constant in duration, and sufficiently high to discharge over the highest buildings in the town.

SECTION III.

Width and Direction of Roads and Streets.—Substructure and Surface.—Paving and Street Cleansing.

256. The drainage and cleansing of the roads, streets, and thoroughfares of a town are acknowledged to be public purposes of the highest utility. The facility of effecting these purposes is dependent upon the several circumstances of the dimensions and situation, and the sub and superstructure of the thoroughfare. The width of the streets is influential in admitting or preventing the access of air and winds, by which the wholesomeness of their condition is largely affected; and also in rendering the process of cleansing by hand or other labour easy or difficult. The direction of roads and streets—vertically in their relative levels and inclina-

tions, and, laterally, in their coincidence with or opposition to the courses of the prevalent winds—is a condition of great importance in affecting the facility and economy of the processes of drainage and cleansing. And the relative dampness and dryness and quantity of debris produced upon any public thoroughfare, are mainly attributable to its construction in the subsoil, and superficial formation.

257. Courts and narrow passages, such as abound in most towns—relics of public ignorance and private cupidity, destined to be destroyed in the progress of enlightened sanatory reformation—limited in width and bounded by elevated buildings, never receive their due share of light, air, or water, and thus present the greatest combination of difficulties to the vital processes of drainage and cleansing. And these purposes can never be economically and efficiently fulfilled until a minimum of width and a maximum of height of buildings are recognised as the elements of street proportion. The recorded and repeated evidence on this point is more than enough to establish the general principle, although the precision of the details requires observations of a more exact nature than have yet been made. It is certain, however, that no street should be less in width than the height of the buildings on either side of it,—that is, that the angle formed by the transverse surface of the street, with a line from its extremity on one side to the summit of the buildings on the other, should never exceed 45°. And in proportion as this angle can be reduced will be the facility afforded for the desirable operation of the air and of such rain as may fall.

258. Provided this principle be strictly observed, the comparative declivity of the surface will become of minor importance. Certainly, the greater the declivity the more rapid and effective will be the action of rains

in cleansing and washing down the debris upon the surface of the street; but it should be the peculiar province of the subterranean sewers constructed beneath to compensate for the relative flatness of the surface, by affording a channel of artificial declivity, that shall at all times free the surface from these matters as quickly and effectually as possible.

259. Connected with the subject of road drainage as applicable in the suburban parts of a town, the necessity of providing *covered* drains cannot be too rigorously enforced. Open road ditches are known to become receptacles for filth and refuse matters of various kinds, and the trouble and expense of cleansing and keeping them in repair, involving a constant making-up of the banks and clearing of the beds, are commonly evaded by a total neglect, which leads to a stoppage of the channels and a constant exposure of decomposing matters, both offensive to the senses and injurious to health. These roadside ditches are frequently, moreover, adopted as the only available channels for dispersing the sewage of the suburban buildings; and being thus converted into open sewers with little or no attempt at formation, and very little care in preserving even their original rude form and capacity, the evils of retaining them are multiplied to a degree actually dangerous to the health of the inhabitants and of passengers.

260. Added to the inefficiency of open road-drains or ditches is the waste of surface which they involve. Pedestrians in the suburbs of towns know well that of a narrow road nearly one-half the width is frequently occupied by a wide and sluggish ditch, and that, in the absence of any raised foot-path, they are frequently driven to a dangerous proximity to its foulness in order to escape destruction by the heedless and perhaps *drunken drivers of* vehicles. If these ditches were

covered and converted into active sewers by the use of pipe-tiles, of comparatively small and yet ample dimensions, space would be afforded for the formation of convenient footpaths on which a walk would become a luxury instead of being a task of danger and annoyance. Those who have "picked their way" along the unpavemented strados of Rome, and contrasted them with the easy security of some of the similarly narrow streets of our own metropolis, will readily appreciate the value of the change which might be thus cheaply effected in our suburban roadways.

261. The quantity of surface wasted by the open road ditches, and the corresponding area thus exposed for the evaporation of stagnant moisture, may be readily calculated from the dimensions of the ditch. It may be safely assumed that for each mile of road at least half an acre of surface is thus, on an average, misapplied.

262. The position of the *main sewers* of a town being beneath and in the same directions as its streets, *these afford the proper channels for discharging the waste water and all other matters from the surface of the streets.* This doctrine is liable to be challenged by all those practical economists who contend that street debris is so injurious in its admixture with the excrementitious matters flowing from a town that it should be scrupulously kept separate, and periodically removed by hand and horse labour above ground. But if we take into the account on one hand the small proportion which the solid part of this debris bears to the total of solid and liquid excrements, house refuse, street drainage, waters, &c., which are universally allowed to be the proper subjects of sewer discharge, and, on the other, form a due estimate of the inconvenience, expense, and disgusting annoyance of removing this street refuse by

any expedient above ground, the result of the calculation will lead, we think, irresistibly to the conviction that the whole of these matters should be by the readiest possible methods delivered into the sewers, and by them conveyed at once to receptacles suitable for their collection and treatment.

263. The exact proportion between the solid street refuse and the total of house sewage and street drainage (which may be supposed to find its way unavoidably into the sewers) is difficult to determine with any certainty approaching to exactness, but an approximate estimate may be formed from such materials as we can command. The excrementitious matters produced by each individual are generally considered to amount to an annual quantity equal to one ton in weight, and the other matters, which are comprised in the total of house sewage and street drainage, may be supposed equal to a similar quantity. We have thus a total equal to two tons annually per head of the population. Now, in the township of Manchester, of which the population in 1841 was 164,000, the number of yards of street-surface swept in the same year was 21,500,000, and the number of loads of these sweepings removed equalled 25,029, each of which is equal to a weight of one ton. Assuming the proportion between the population and street-surface of this township to be a fair average for most towns, we have thus a total of house sewage and street drainage equal to $164{,}000 \times 2 = 328{,}000$ tons, and a total of street sweepings equal to 25,029 tons, being $\frac{1}{13}$th of the former, or less than 7·7 per cent. This rough calculation will be quite sufficient to show the small proportion in which the manuring value of the sewage is liable to be injured by the admixture with it of the street debris in the common receptacles or

sewers, and the consequent inadvisability of engaging in the expensive operations of carting and removing this debris by any combination of human and animal labour.

264. Arrangements for the purpose of discharging the street surface-drainage into any contiguous river or other watercourse instead of allowing it to mingle with the sewage in the receiving wells or receptacles to which they are both conducted by the sewers, may, if thought necessary, be provided as accessory apparatus in connexion with the wells, although it is highly probable that the growth of our experience on this subject will develop preferable methods of treating and disposing of these matters by subsidence and chemical processes.

265. The amount of street debris, or the quantity removable from any extent of surface, is found to vary most materially, according to the structure of the street or roadway. Thus, roads formed of broken granite or other similar materials are rapidly destroyed by the action of wet, which loosens the superficial coating of the road, and passes into the body of the materials; the finer particles also become washed upon the surface, and act as sand in grinding it down, by the action of the wheels upon it. Paving formed with stones of irregular shapes and sizes is also productive of a large quantity of debris, although less than the unpaved surfaces just referred to; upon this inferior class of paving water acts destructively by washing up the soil and dirt between the stones, by which they become loosened, while a great proportion of these interposed materials have to be removed as they appear upon the surface in the form of mud. Pitch paving formed with squared blocks of granite, whin, or other stone of equal hardness and durability set in lime grouting upon a

substantial foundation of concrete 9 to 18 in. in thickness, according to the nature of the substratum, forms the most permanent construction for the carriage-ways of streets and thoroughfares, and affords a correspondingly small proportion of materials to be removed from the surface in order to preserve its cleanliness. Wood paving yields the minimum of debris, and its economy, as a subject for the labours of the scavenger, at any rate is thus very great, as compared even with the most perfect form of stone-paving.

266. By making the sewers thus directly available for one of their proper purposes, that of receiving the waste matters from the streets and thoroughfares, the operation of street cleansing is reduced to mere sweeping of these matters to the side channels, which should be constructed so as to afford a ready passage for them to the sewers beneath. The economy thus obtained by dispensing with the raising and carting to distances sometimes extended may be inferred from the fact, that the average expense of sweeping and carting away the refuse of 1000 square yards (in Manchester) in 1843 was 4*s.* 6*d.* This was performed by the ordinary hand labourers or sweepers. In London, at the same date, the mere *sweeping up* of the refuse from the surface of Regent Street, and depositing it in the street in loads for another process of removal, was charged at the rate of 1*s.* 2*d.* per 1000 square yards, as executed by Whitworth's patent machine. The mere *sweeping* may be liberally estimated to cost 9*d.* for the same extent of surface, and thus $\frac{5}{6}$ths of the entire expense of street cleansing might be avoided by adopting the sewers for the purpose suggested.

267. Although we advocate the abandonment of all apparatus for carting and removing street refuse, it may

be useful to describe briefly the "Patent Street-Cleansing Machine," invented by Mr. Joseph Whitworth, which has been applied to a considerable extent in Manchester and elsewhere, and been considered a very promising contrivance. This will be best done by quoting the inventor's own description of his machine, as rendered in evidence before the "Commissioners of Inquiry into the state of large towns and populous districts" in 1843. "The principle of the invention consists in employing the rotary motion of wheels moved by horse or other power, to raise the loose soil from the surface of the ground, and deposit it in a vehicle attached. The apparatus for this purpose consists of a series of brooms suspended from a light frame of wrought iron, hung behind a common cart, the body of which is placed near the ground for greater facility in loading. As the cart-wheels revolve, the brooms successively sweep the surface of the ground, and carry the soil up an incline or carrier-plate, at the top of which it falls into the body of the cart. The apparatus is extremely simple in construction, and has no tendency to get out of order, nor is it liable to material injury from accident. An indicator, attached to the sweeping apparatus, shows the extent of surface swept during the day, and acts as a useful check on the driver. It also affords the opportunity of working the machine over a given quantity of surface. The average rate of effectual scavengering by hand in Manchester, taken for a whole year, is from 1000 to 1500 square yards of surface daily for each scavenger. The manner of sweeping is different in London, and therefore an apparently larger amount of work is done, but not so effectually. When the machine is in operation, the horse going only 2½ miles per hour, it sweeps during that time 4000 square yards;

thus performing in a quarter of an hour nearly the day's work of one man. The average amount of surface which can be swept by a machine during the day depends upon the distance of the places of deposit. In Manchester we have seven places of deposit, and the average number of yards swept daily, by a machine drawn by one horse, is from 16,000 to 24,000."

SECTION IV.

Main Sewers; Proportions and Dimensions, Inclinations, Forms, and Construction.—Upper and Lower Connections.—Means of Access and Cleansing.—Adaptation for Street Cleansing, &c.

268. In drainage, as in many other subjects, controversy has frequently been found to be excited upon those very details of the art which appear to be the most simple and the most readily deducible from observation, while the proper ground for discussion, in which it is really urgently needed in order to determine general principles and mark out leading rules, has been left nearly or quite unoccupied. Thus the forms, sizes, and thicknesses of sewers have received the most elaborate investigation, and provoked the expression of the most widely differing opinions; while the principles of arrangement according to which the entire system should be laid out, and the great questions of the most healthful and economical disposal of the refuse of towns have, till lately, remained unsought and unasked. Misled by an instinctive adoption of the works of our forefathers, we have been content to build our sewers in old channels, and to put patch upon patch—add length to length of sluggish sewer or practical cesspool, in order to maintain ancient outfalls, while the subsidiary details of form and capacity have become the vexed

questions and grounds of issue among the most practised advisers.

269. Not that the attention given to the details, and the neglect inflicted upon the general principles are here contrasted for the purpose of denying the importance of the former, but that, had the principles been first determined, the details would be found readily deducible from them in a manner and with a certitude admitting little dispute or discussion.

270. We have already, in the first Section of this Division, shown the general principles upon which the drainage of towns should be arranged with reference to the inclinations of surface, and the means of discharging and disposing of the sewage. From these principles it immediately follows that the proper functions of sewers are twofold and *twofold only*, viz., the conveyance and collection of house-drainage and of street-drainage. In the former are to be included the drainings of roofs of buildings and of yards or other spaces attached to them. In these two purposes is thus comprised the superficial drainage of each entire town. Any attempt to add to this the drainage of the sub-formation is a mistaken and a supererogatory aim. This position will be denied by those who advocate the *under-drainage* of London as one of the purposes of its sewerage. Let us endeavour to understand the practical value of this purpose, and thence deduce the infinitely small amount that would be mis-spent in any attempt to realize it. If the proper functions of sewers be effectually discharged, viz., the conveyance away from a town of all the rain-water that falls upon its surface, and of all the solid and liquid refuse produced in streets and buildings, what will be the amount of sub-moisture which it can be necessary or desirable to ab-

through them, they should be at least 2 ft. in width, and, to allow crawling through, 2 ft. 4 or 6 in. in height, to allow his crouching through, 3 ft. 6 in., or to stoop through, 4 ft. 6 in. The thickness of brickwork of these sewers should not be less than 9 in., nor the depth from the ground less than 12 ft. at the shallowest part, in order to provide for the drainage of a basement story about 7 ft. 6 in. in height. Assuming 2 ft. 6 in. as the minimum height for a common sewer, and allowing 20 in. of deposit to exist in a public sewer before it can rise into the common sewers, the surveyor deduced a minimum height for public sewers of 4 ft. 2 in.

273. In the Westminster Division of Sewers the level of the outfalls into the river varies from 10 to 15 ft. below the level of high-water mark, and some of them have flaps. Some of the main sewers have *a fall of only half an inch to* 100 *ft.* The form of the sewers is that of a semi-circular arch at the top, and a segmental invert with upright sides. The two sizes used are—first-class, 5 ft. 6 in. high and 3 ft. wide; and, second-class, 5 ft. high and 2 ft. 6 in. wide. The three centre courses of every invert are built in cement, and the remainder of the work in Dorking lime-mortar. The walls are 1½ brick in thickness, and the arch and invert 2 half-bricks, or 9 in. The cost for a sewer 3 ft. wide is, for the brickwork, 14*s.* 3*d.* per ft., and for a sewer 2 ft. 6 in. wide, 12*s.* 6*d.*

274. The sewers throughout the Holborn and Finsbury Divisions discharge into the main sewers of the City of London, and have no outfalls of their own into the Thames. The Fleet sewer conveys the drainage of about 4444 square acres of surface in those divisions, and is calculated to receive annually from this surface

about 100,000 cube yards of matter held in mechanical suspension, and carried to the Thames by the force of such waters as flow through the sewer; these waters, by the experiments of Mr. Roe, having been found to amount to about 100 times the bulk of the matters held in suspension by them. It follows, therefore, that the Fleet sewer discharges from this surface about 10,000,000 of cube yards of sewage-water and suspended matters into the river Thames annually. The total work of this sewer comprises also the quantity it receives from the surface of the City after passing through the district here referred to. A sewer carried up to Holloway, in this division, a length of nearly 3 miles, passes under Canonbury (Islington) at a *depth of 68 ft. from the surface*, and the drainage of the houses in that part is provided for by a *subsidiary sewer*.

275. Sewers constructed on the Kingston estate, through a very soft clay, are built of an oval form, the largest size being 3 ft. 6 in. high, and 2 ft. 6 in. wide, the radius of the side curves about 3 ft., half a brick thick in cement. The extent of cutting was from 16 to 18 ft., and the cost 15*s*. per lineal foot. The fall at the rate of 80 ft. in a quarter of a mile.

276. The practice in some of the provincial towns was reported as follows:—

Fig. 63.

Lancaster.—Flag or slate bottom. Rubblestone sides, laid in common mortar. Rough stone covers. Mains 2 ft. 6 in. × 1 ft. 4 in., 6*s*. per lineal yard. Branch-street drains, 1 ft. 4 in. square, 4*s*. 6*d*. ditto. Yard drains, 6 or 7 in. square, 2*s*. ditto. All found to be very inefficient.

Fig. 64.

Nottingham. — Brick. Cylindrical sewers. Upper half built in mortar. Lower half laid dry. Half-brick thick. Diameter from 2 ft. to 2 ft. 6 in. Average cost 7*s.* per lineal yard.

Birmingham and Walsall.—2 ft. circular culverts laid 5 ft. deep. 7*s.* per lineal yard.

Chester.—Circular brick drains from 30 to 36 in. diameter. Average cost 12*s.* per lineal yard.

Bristol. — Four sizes of elliptical brick sewers.

	Ft.	in.		Ft.	in.	
1st.	. 4	0	×	3	0	Internally.
2nd.	. 3	3	×	2	6	
3rd.	. 2	8	×	2	0	
4th.	. 2	0	×	1	6	

All 9 in. thick.

Fig. 65.

Cylindrical drains, 1 ft. 2 in. in diameter internally, 7 in. thick.

Rate of fall from 1 in 60 to 1 in 360.

Frome.—Stone and lime cheap and abundant. Drains or "gouts" 18 in. square, covered with stone to take any weight, exclusive of digging, 2*s.* per lineal yard.

Culverts 2 ft. square, dry walls, with rubbed stone arch, turned in good coal-ash mortar, exclusive of digging, 4*s.* 9*d.* per lineal yard.

Swansea.—Oval drains, 3 ft. 2 in. × 2 ft., including excavation, 10*s.* 6*d.* per lineal yard.

Cylindrical drains, 2 ft. diameter, including excavation, 8*s*. per lineal yard.

Brecon.—Cylindrical drains, 2 ft. diameter, cost 8*s*. per lineal yard.

Square drains, side walls of dry masonry, with flat covering stone, from 3 to 4 in. thick.

Cost.—12 in. 2*s*. 6*d*. per lineal yard.
15 in. 3*s*. 3*d*. "
18 in. 4*s*. "

277. The egg-shaped or oviform section used in the Holborn and Finsbury divisions is shown in fig. 66, and the section commonly used in the Westminster division, up to the year 1843, is shown in fig. 67. The

Fig. 66.

Fig. 67.

difference in expense between sewers of these sections has been estimated at 1660*l*. per mile, upon the following data. Brickwork at 20*s*. per cube yard. Excavation 1*s*. per cube yard. Filling in 3*d*. per cube yard. Carting 2*s*. per cube yard. Remaking surface 1*s*. 6*d*. per *superficial* yard. Average depth of excavation, 20 ft. The

quantities per mile of each sewer are shown in the following table; the size of the egg-shaped sewer being 5 ft. 3 in. by 3 ft. 6 in., and that of the upright-sided sewer 5 ft. 6 in. by 3 ft.

	Finsbury, or Egg-shaped Sewer.	Westminster, or Upright-sided Sewer.
Bricks consumed	924,140	1,378,080
Cube yards of brickwork . .	2,272	3,388
Do. do. of excavation . .	19,555	25,420

Excess in Westminster Sewer, per mile.

1116 cube yards of brickwork at 20*s*. . . .	£1116	0	0
5865 " " excavation at 1*s*. . .	293	5	0
5865 " " filling-in at 3*d*. . .	73	6	3
1116 " " carting at 2*s*. . . .	111	12	0
880 super. yards repairing at 1*s*. 6*d*. . .	66	0	0
Total	£1660	3	3

278. One of the Westminster sewers, built in the Harrow Road, according to the section, fig. 67, failed, owing, as alleged, to some difficulties in the nature of the soil and to imperfect workmanship. This was replaced by another form of sewer, which is shown in

Fig. 68.

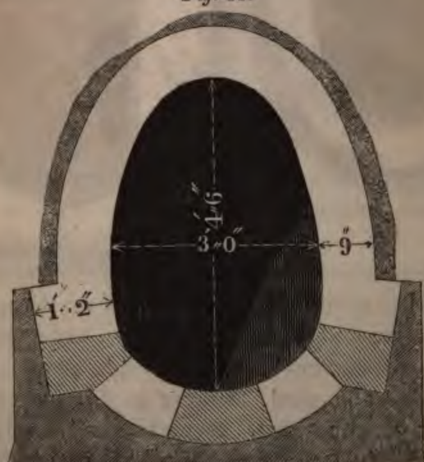
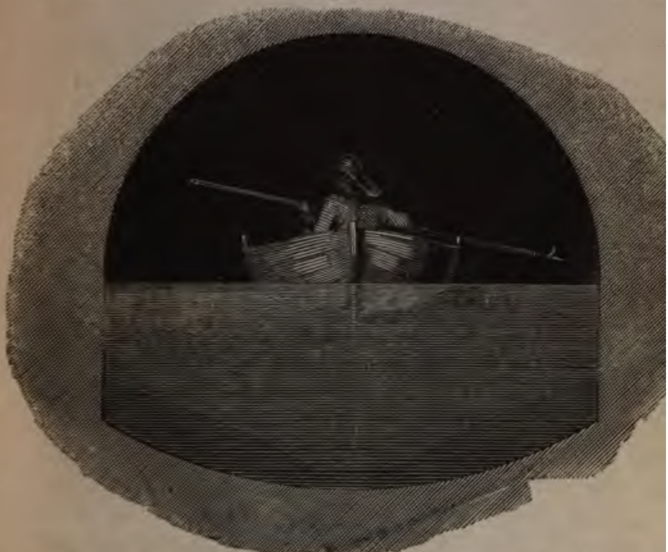


fig. 68, in which the shaded parts represent brickwork in cement, the invert and springers being bedded in concrete as high as the 14-inch work as there shown.

279. By way of conveying a ready idea of the vast size of the Fleet sewer, the great length and extended functions of which have been before noticed, the two figures 69 and 70 are introduced, the one showing the

Fig. 69.



section of the sewer at the city boundary, where its dimensions are 12 ft. 3 ins. by 11 ft. 7½ ins., and the other showing the size of the mouth of the sewer, which is 18 ft. 6 ins. by 12 ft., and of ample capacity to *admit one of the largest locomotive engines*, the gigantic dimensions of which are sufficiently familiar to all who have found it necessary to cross the platform of a railway station. Yet this sewer "has often been sur-

charged; and only within the last year (1842) the culvert, so ably constructed at its mouth by Mr. James Walker, was severely injured by the flood consequent upon a thunderstorm."*

280. The *capacity* of sewers is determined by a consideration jointly of the *quantity* of sewage to be conveyed through them, and of the rate of inclination or *fall* in their vertical position. The capacity will vary directly as the quantity and inversely as the fall; since the greater the fall the more rapid will be the discharge. It has been usual to prescribe another limitation as to the minimum capacity of sewers, viz., that they shall at least, under all circumstances, be large enough for a man to pass along them. The necessity for this allowance has arisen from the fact, that sewers are found to require cleansing by hand; that it is utterly impossible to remove the accumulations which are liable to occur within them by any other means, and thus some 10,000*l*. has been annually expended in London alone in an employment of a most disgusting and dangerous nature. We have no hesitation in saying, that under a thoroughly efficient and practicable system no such process could ever be needed, and, moreover, that if deemed desirable for any possible purpose, it would apply only to the principal sewers, the size of which would admit of it, as determined upon the joint data of *quantity* and *fall alone*. We will, therefore, dismiss this condition from the problem, and study it upon the two data named.

281. Since the quantity of sewage due to any given extent of surface will depend mainly upon the amount of population to be served, it follows, that in an equalized

* Evidence of the Surveyor to the City Commission of Sewers, before the "Commissioners of Inquiry into the state of large towns and populous districts." (1843.)

Fig. 70.

system aiming at an uniform size for the sewers of the several classes, the points of collection or receiving wells should be arranged at distances varying inversely as the density of the population. Now, the *maximum* density of the population of London is estimated at 243,000 to a square mile. Let us suppose the drainage *of one* quarter of a square mile of surface, populat-

to this extreme degree of closeness, to be conveyed in *one main sewer*, and endeavour to form a rough notion of the total quantity of sewage which this sewer should be fitted to convey and discharge. The entire bulk of sewage must consist chiefly of the house-sewage and rain-water from the surface—at least the other constituents are of too insignificant an amount to require notice in a merely approximate estimate. And similarly the entire house-sewage may be assumed as equal to the bulk of water delivered to the total population. We have calculated, in Section II., on the supply of water (par. 217), that 20 gallons are or ought to be allowed to each individual of the population per diem. The annual quantity will, therefore, be $20 \times 365 = 73,000$ gallons, or say 1200 cubic feet. The population of the square quarter of a mile being $\frac{243,000}{4}$, or about 60,000, this number multiplied by 1200 cubic feet for each person will produce 72,000,000 as the annual quantity of sewage in cubic feet arising from this population. To this is to be added the bulk of the rain water, which we will allow to amount to 24 inches, or 2 ft. in depth annually over the surface, and that this quantity will be discharged into the sewer without further diminution by evaporation. The total quantity to be drained annually from the surface of the quarter of a square mile will thus amount to $2640^2 \times 2 =$ 13,539,200 cubic feet. Adding this, which we will call $13\frac{1}{2}$ millions to the 72 millions of house sewage, we obtain a total of $85\frac{1}{2}$ millions of cubic feet of sewage to be discharged per annum from the surface of a quarter of a square mile of the most densely populated part of the metropolis. If this annual quantity were in a state of constant transition along the sewer, and with equal

velocity throughout, and the effect of friction was for the moment disregarded, the proportion to be passed per minute would be of course easily calculated, being 85,500,000 divided by 525,600 (the number of minutes in a year), or 162·66 cubic feet. Now a recorded fact will be a more useful datum for our calculation here than any elaborate investigation of velocities, friction, &c.; and we will therefore refer to the experiments of Mr. Roe, instituted for testing the value of the flushing system as applied to sewers, and which showed that the sewage passed through the river Fleet sewer with an average velocity of 83·47 ft. per minute; the run of water being spread over a surface 10 ft. in width and the stream being only 10 ins. in depth, the passage every minute, therefore, was equal to 692·8 cube feet of sewage, and the friction in this case being greater than if the same sectional area of water had been accumulated in a cylindrical drain of smaller diameter. The solid matters held in suspension by this water amounted to the proportion of 1 in 96 of the bulk of water, and consisted, as all sewage usually does, of decomposed animal and vegetable matter, and detritus from streets and roads. At this rate of transit, it appears that a sectional area equal to two square feet would suffice to pass the entire sewage of a thickly populated area of a square quarter of a mile, supposing the passage to be constant and uniform, and the fall of the sewer and friction of the sewage equal to that of the river Fleet sewer, on which the experiments were made.

282. In modifying this result to provide for the difference between the assumed and the real nature of the transit, we will first admit that the bulk of the sewage, consisting of that flowing from the houses, is delivered into the drains during perhaps half the real time;

that is, during 12 instead of 24 hours. The sewers will therefore be required to discharge double the quantity estimated during each alternate period of 12 hours, and during the intervening periods of like extent to remain empty. We will therefore double the capacity, and allow four square feet of transverse sectional area of main sewer for the drainage of the given surface.

283. But we have another allowance to make;—we have the "*storm* waters" to provide for, about which we have heard so much, because occasionally during the rainy month of July a smart shower is observed to cover a flat street, or form ponds on the low side of an ill-formed roadway. Let us estimate the allowance required for this phenomenon and infer the advisability of providing for it in the sewers. We have seen that 24 inches in depth of rain falling upon our selected spot will equal a total bulk of $13\frac{1}{2}$ millions of cubic feet. We will suppose an extraordinary case, viz., that some July day, the whole quantity due to a month (2 inches) falls in 20 minutes. Then, in order to prevent any flooding of the thoroughfares, this quantity, equal to $\frac{13,500,000}{12} = 1,125,000$ cubic feet will have to be disposed of in 20 minutes. Assume that the velocity produced by the pressure on the water will equal 1000 ft. per minute. What would be the capacity of the sewer equal to discharge this rain water as rapidly as it falls from the clouds? The quantity accruing per minute being $\frac{1,125,000}{20} = 56,250$ cubic feet, and the velocity equal to 1000 cubic feet, the capacity of the sewer must be equal to $56\frac{1}{4}$ square feet of transverse sectional area. Now, we have found that an area of 4 ft. will suffice ordinarily for the house sewage. Is it desirable to

increase the capacity of our sewers *fourteen fold* in order to provide for an occasional shower? There can be no necessity to answer the query. Economy of the most liberal disposition would not sanction any such arrangement. If the exact area of 4 ft. be doubled in order to make ample provision for all ordinary contingencies, it will satisfy every reasonable requirement; and then by suitable inlets to the sewer, the deluge of rain waters will be prevented from overcharging it, and the effects of the shower will disappear in some hour and a half, and before any very serious mischief can be produced by the water soaking into the subsoil through well paved streets and yards.

284. In proportion as the population is more extended, the ratio of house-sewage to surface-sewage will of course diminish, and *vice versâ;* but we believe that economy and facility of drainage will be best promoted by limiting the sum of population and area to each receiving well, so that a transverse sectional area of 8 or 9 ft. shall suffice for the main sewers.

285. In the suburban districts of a town where comparatively large surfaces exist in gardens, and where therefore the effect of allowing the "storm waters" to gather might be productive of mischief by saturating the soil, the diminished amount of house-sewage will tend to make the operation of the mains more effective in relieving the surface, besides which natural declivities will usually aid the fall of the sewers; and provision might frequently be made at little cost for receiving the surface-water in auxiliary wells, or receptacles in which it could be made available for subsequent service in irrigation, without allowing it to burden the main sewers of the district.

286. Having based our calculation as to the capacity

of main sewers upon an area of the maximum density of population, we will, with the same view of providing for the utmost necessities, consider the question of declivity or fall as to be applied to that description of natural surface which presents the greatest difficulties to the operation of any system of sewage—a perfect or dead level. The wells or receptacles for the sewage being placed half a mile distant from one another, so that the area drained into each of them equals a square quarter of a mile (or each side 2640 ft. long), half of this, or 1320 ft., may be taken as the length of each of the main drains. The longest of the main sewers thus measuring 1320 ft., the fall is to be computed with reference to this length. We have seen that metropolitan sewer-practice has recognised a fall of half an inch in 10 ft., or 1 in 240, as sufficient for all the purposes of good drainage. At this rate the fall due to 1320 ft. will be 5½ ft. But preferring to allow double this fall as proportionally improving the system, by aiding the discharge, we should require a fall of 11 ft. in our main sewers of the maximum length. And preserving 5 ft. above the head of the main, it would lie at a depth of 16 ft. at the well. This 5 ft. will usually be found sufficient to allow all necessary fall in house-drains and in branch sewers, to serve the *superficial* draining of the intervening district.

287. The utmost economy of the system would be attained by multiplying the main sewers as much as possible, as by this means the length of the branches may be reduced to a considerable extent, and the necessary depth of the mains also reduced correspondingly. On the other hand, by sparing the main sewers they are required to be laid deeper, and the branches also; or, if depth be saved, it is at the expense of efficiency,

and the whole system is instantly filled with insuperable difficulties in vain attempts to reconcile the relative levels of an infinite number of collateral sewers, and to adjust the details of the arrangement to the minor variations of surface above.

288. In the depths we have assumed as deduced from the desirable rate of inclination for the main sewers, allowance is not yet made for draining the basement stories of the buildings. It must be confessed that this purpose involves the greatest difficulty in the details of the system. On the one hand, it is evident that the construction of sewers as large as rivers, and at depths varying from 20 to 70 ft. below the surface, demands a most extravagant expenditure at the outset, and after all, puts the works in positions which are practically inaccessible. Yet, on the other hand, we shall be reminded that the deep basements and kitchens must be provided for, and that our branch sewers must be sunk low enough to serve even the lowest of these. In order to provide for these, the main sewers will need to be laid some 8 or 10 ft. lower than the depths we have given, viz., 13 or 15 ft. at the head, and 24 or 26 ft. deep at the well. Rather than permit the evils caused by sinking sewers at these depths, it will probably be preferable to reduce the distance between the wells, or even admit (although highly objectionable) some diminution in the rate of fall. We are satisfied, however, that the fullest investigation into this subject will establish the principle *that no sewage matters of any kind whatever should be allowed to be discharged from a house into a drain below the surface of the ground.* The difficulties which would attend any attempt to carry this principle into effect in London and similarly ill-constructed cities may be too formidable to be now encountered, but they must be overcome

before the sewerage of such towns can be reformed upon the most efficient plan which our present knowledge and experience suggest.

289. The dimensions of the branch sewers are to be determined upon the same two elements of population and surface to be served that we have referred to in estimating the required capacity for the mains, and, according to the varying extent and proportion of these elements, a scale of sizes may be determined for the several lengths, distances apart, &c., of the branch sewers.

290. By the system of district collections here recommended, one great difficulty felt in planning sewers for concentrated discharge is at once obviated. In forming sewers which are intended at the time to serve a certain district, but which may hereafter be treated as trunks, and called upon to discharge constant accessions of sewage from an extending neighbourhood, no calculation can possibly be made as to the sufficiency or otherwise of the section it is proposed to adopt. Thus, as truly remarked by the Surveyor to the City Sewers Commission, "the sewer from Moorfields to Holloway appears to measure upon the map about *three* lineal miles. In process of time, and as buildings increase, it may throw out branches in all directions, and the *three* miles may become *thirty*. Not only all the atmospheric waters which may, upon an average, fall within the valley south-eastward of Highgate (or at least a large portion of them), but all the artificial supplies which the wants of its yet future inhabitants, as well as of those intermediate between Islington and Moorfields, may require, will have to be carried off by the City sewers." The necessary consequence of which doubtful condition is, either that the sewers are at first constructed in a most extravagant manner as to dimensions *and depth, or that* they are afterwards found to be

utterly inadequate to their increased duty, and have to be reconstructed at greater depth and of enlarged capacity. Whereas if district collections are adopted, each main sewer is at once properly devised as to size, form, and construction, and continues to perform its services efficiently; and, as new districts are formed, each of them is provided with another system of sewers adapted to its defined limits, and made sufficient for all the work it will be ever expected to perform.

291. In the *form* of sewers two conditions have to be fulfilled, viz., *strength*, as obtained with economy of cost, and *efficiency of action*. A hollow channel embedded in the subsoil is evidently liable to be pressed upon and against by the weight and bulk of the surrounding solid materials, and it therefore becomes necessary that the form of this channel be such as will enable it to resist effectually this pressure from without. We all know that a curved form of construction, in which the convex surface is opposed against the pressure, is stronger in this way than a plane surface, because the pressure applied to any point of the convex surface is immediately distributed to all the surrounding points on that surface, and their combined resistance is thus brought into action against the external force. And since the complete co-operation of all parts of the surface in resisting *uniform* pressure from the exterior is obtained only when all those parts have a common centre, the circle is the most perfect figure for this purpose.

292. But the pressure upon all parts of a sewer is not uniform. The top of it will be subject to the entire weight of the mass above it, minus only the friction and structural tenacity by which that mass is prevented from moving freely downward from the surrounding portions. The sides of the sewer are pressed against by the soil with forces inversely proportional to the

tenacity of the material; that is to say, the less the tenacity or power of self-support, the greater will be the pressure against the sewer. The bottom of the sewer may be regarded as free from external pressure, except such as is due to the resistance with which the soil below meets the downward pressure exerted by the sewer itself, and transmitted by it from the load above.

293. The greatest pressure being thus vertically from above, a form of uniform strength would require to act with greater resistance in this direction. Hence an elliptical form, the longest diameter being placed vertically, would appear to answer the conditions better than a circle, and is, doubtless, the least imperfect form that can be adopted. Practically it has been deemed desirable to combine, as far as possible, a considerable capacity with the means of making a reduced flow active in its passage through the sewer; and these requirements appear to be fulfilled by a form of section that differs from an ellipse in having the upper curve of larger radius than the lower one, resembling the outline of an egg standing on its smaller end, and to which the name of egg-shaped, or oviform, has therefore been applied.

294. The value of the curved bottom of reduced radius depends upon the well-known law, that the passage of fluids through channels is retarded by the friction between the water and the surface of the channel with which it is in contact. And it is an evident result of this law, that the greater the surface of contact the greater the friction. Hence any given bulk of water will flow the most rapidly in that form of channel in which this surface of contact is reduced to the minimum. The form necessary to fulfil this condition is presented at once by the well-known geometrical principle, *that the circle* includes a greater area within its

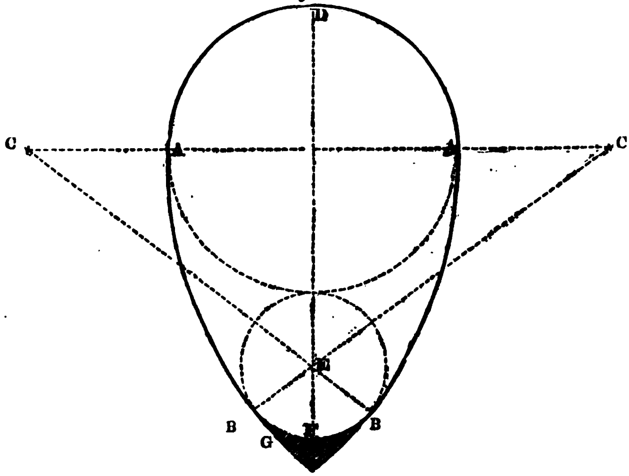
perimeter than any other figure of equal perimeter. And as the necessity for aiding the flow by diminishing the friction occurs chiefly when only a small stream exists within the sewer, it follows that the radius of curvature should be proportionally reduced within practical limits.

295. The exact proportion which the radii of the upper and lower curves of the oviform section of sewer should bear to each other (adopting circular curves as preferable in practice to elliptical or any indefinite curves) would depend on the precise average minimum of water to be provided for, calculated jointly with the density and tenacity of the soil, and the depth at which the sewer is laid. As it is manifestly impossible to determine all these elements with exactness in evolving any general rule for the proportions of the section, they may be disregarded, since the main form is established by the conditions stated in paragraph 293, and a practical rule may be formed which will be found to answer all real purposes.

296. In the forming of sewers, as in all works of a similar class, which are often necessarily entrusted, to a great extent, to the charge of workmen, who cannot be expected to pay much attention to the refinements of geometrical principles, *simplicity* is evidently an object of the first importance. The proportions of the several curves required in marking out the section and forming the moulds and gauges to be used in constructing and testing the work should be such as can be readily understood and exactly remembered; and in proportion as these rules are observed in designing the form, will be the probability of that form being preserved and exactness attained in the construction of the sewer.

297. In seeking this object we have worked out a diagram of proportions, shown in fig. 71, that we can venture to recommend on the score of simplicity and

Fig. 71.



sufficiency, which we hope will be made evident by the figure and the following description. In this section let the diameter A A, of the upper semicircle A D A equal 1; that of the lower arc B B will equal ·5. The entire height of the section D F will equal 1·5, and the radius C A A, of the side arcs A B (truly tangential to the upper and lower arcs) will also equal 1·5. The centres C C being upon the produced diameter of the upper arc, that arc will equal a semicircle, and the lower arc B B will equal 120°, the points for the meeting of the curves being at B B, found by drawing the radial lines, C B, through the centre E of the lower arc. Suppose the greatest diameter A A be determined at 3 ft., the several dimensions will be thus:—

	Ft.	In.
Diameter of upper arc	3	0
Do. of lower arc	1	6
Height of section	4	6
Radius of side arcs	4	6

And the area may be taken (as a very close approximation to the truth) as equal to that of a semicircle of 3 ft. diameter, added to the area of a circular segment whose radius is 4 ft. 6 in., and versed sine 1 ft. 6 in.; the area thus given being in excess only the small space shown in shaded lines at G.

298. The *construction* of sewers is varied according to their size, and should be also considered with reference to the economy with which different materials may be obtained according to the locality of the district, and also the nature of the soil in which the work is constructed. For the smaller sewers the "glazed stone ware" pipes are found efficient substitutes for those built up of brickwork. They have the advantages of being much more quickly laid than the others can be built, and of presenting a very superior surface for the rapid passage of the sewage. They are also constructed in various forms of bends and junction pieces, and thus afford the means of ensuring proper form in these points. From their comparative thinness, pipes of this kind afford a much larger capacity with a given quantity of excavation for laying them, than sewers formed of brickwork, which, even for the smallest diameter, cannot be less than half a brick, or $4\frac{1}{2}$ in. in thickness. In laying them care must, of course, be taken with the joints, which are formed by a socket on one end of each length of pipe in which the plain end of the adjoining length is received. The prices at which

these pipes may be procured in London are as follows:—

Straight Tubes with Socket Joints.

	Inches Bore.	Price per Lineal Foot.	
In 3 ft. lengths	2	0	4
" "	3	0	5
2 ft. "	4	0	6
" "	6	0	8
" "	9	1	1½
" "	12	1	10
" "	15	3	0
" "	18	4	0

Diameter of Bore.	Bends Each.		Junctions Each.		Double Junctions Each.	
Inches.	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
2	1	0	1	0	1	4
3	1	3	1	3	1	8
4	1	9	1	6	2	0
6	2	3	2	0	2	8
9	3	6	3	6	4	6
12	5	6	5	6	7	0

Egg-shaped tubes are also prepared of the same material in 2 ft. lengths with socket joints, at the following prices:—

Size Inside.				Price per Lineal Foot.	
Ft.	In.	Ft.	In.	*s.*	*d.*
1	8 ×	1	0	3	6
1	3 ×	0	9	2	3
0	9 ×	0	6	1	1

The prices in Manchester of the egg-shaped tubular sewers, and of brick sewers of equal capacity, are as follows, exclusive of excavation in both cases:—

Sizes.		Tubular Sewers per Lineal Yard.		Brick Sewers per Lineal Yard.	
Ins.	Ins.	*s.*	*d.*	*s.*	*d.*
12 ×	9	4	6	2	6
16 ×	12	7	6	3	0
20 ×	15	10	6	3	6
25 ×	18	15	0	4	0
29 ×	21	21	0	4	6
36 ×	24	27	0	5	0

The prices in Manchester of brick sewers lately constructed, including excavation of the maximum depth of 10 ft., are as follow:—

Inches.	*s.*	*d.*	
42 × 24	17	3	per lineal yard.
36 × 24	15	4	„
33 × 22	15	0	„
30 × 20	14	0	„
24 × 18	13	4	„
20 × 15	12	6	„
15 × 12	8	3	„

In Chester the following prices have been paid, including excavation of the maximum depth of 12 ft.:—

Inches.	*s.*	*d.*		
42 × 32	11	0	per lineal yard,	ordinary earth.
42 × 32	15	2	„	rock.
36 × 28	9	6	„	ordinary earth.
33 × 25	8	6	„	„ „
30 × 22	7	9	„	„ „
24 × 18	6	6	„	„ „
20 × 15	5	6	„	„ „
15 × 12	4	9	„	„ „

The stone-ware tubes may be manufactured with ample strength for all purposes required in their application as

minor sewers. Some experiments made with specimen tubes of fire-clay at Glasgow, proved their power to resist a pressure equal to that of a perpendicular column of water 900 ft. in height, being three times the pressure to which it is found necessary to prove iron pipes used for the transmission of water. Drain tubes of common clay are supplied in Glasgow at the following prices:—

	s.	d.	
3 in. diameter . .	0	6	per lineal yard.
6 " . .	0	9	"
9 " . .	1	0	"
12 " . .	1	3	"
18 " . .	2	0	"

Pipes of fire-clay at Glasgow, cost:—

	s.	d.	
4 in. diameter . .	1	0	per lineal yard.
6 " . .	1	6	"
12 " . .	2	3	"

Supplied in large quantities, it is presumed that all of these prices for tubular drains would admit of considerable reduction. The following estimates for works, as ordered by the Metropolitan Commission of Sewers in the months of April and May of the present year, contain some useful figures as *to the cost of works of this class*:—

Quantities.	Localities.	Estimated Cost. £	s.	d.
245 ft. of 12 in. pipe sewer . .	To be put down an open sewer in Southampton Street, Nine Elms, Surrey	39	0	0
400 ft. of 9 in. and 500 ft. of 12 in. .	To be put down in St. Mark's Road, Kennington	131	5	0
485 ft. of 12 in. . .	To be put down in James Street, Kennington	78	16	3
400 ft. of 9 in. and 415 ft. of 12 in. .	To be put down on the south side of Kennington Common	117	18	9
700 ft. of 4 in. . .	To be put down on the north side of Kennington Common	15	0	0

483 ft. of sewer, 3 ft. 6 in. by 2 ft. 3 in.	To be put down in the Wyndham Road, Camberwell	157 0 0
95 ft. of 18 in. pipe sewer	To be put down in Great Guildford Street, Borough	28 10 0
135 ft. of 15 in.		26 0 0
665 ft. of 9 in. . . .	In an open ditch	78 10 0
800 ft. of half-brick sewer, 3 ft. 6 in. by 2 ft. 3 in. and 158 ft. of 12 in. pipe sewer		300 0 0
240 ft. of 9 in.		15 0 0

From these estimates the average costs of supplying and laying the pipe sewers of several sizes appear to be as follow:—

	s.	*d.*	
4 in.	0	5·14	per foot.
9 in.	1	3	"
12 in.	3	3	"
15 in.	3	10	"
18 in.	6	0	"

And of the egg-shaped sewer, half a brick thick, and measuring 3 ft. 6 in. by 2 ft. 3 in., 6*s.* 10½*d.* per foot.

299. In commonly good soils brick sewers may be constructed of a single half brick, or 4½ in. in thickness, of curved form, of considerable size. In the Finsbury division, half brick egg-shaped sewers have been constructed, 4 ft. 6 in. by 2 ft. 9 in., and are found sufficient. Sewers of these dimensions would be ample for the mains of properly limited and defined districts. If the soil be of a loose and uncertain character, it will be necessary to build them 9 in. in thickness, or two half brick rings. In the small curve of the invert all brick-built sewers should be very carefully constructed, the unavoidable interstices between the bricks (if of the common square form) being filled in with pieces of slate or tile, and the whole floated in with cement to make it as one solid mass. If this be not honestly done and carefully superintended, the action of the declivity will

be nullified by irregularities in the interior surface of the waterway, and a liability created to the formation of bars by the settlement of the solid portions of the sewage. Egg-shaped sewers 3 ft. 6 in. by 2 ft. 6 in., in an average excavation of 15 ft., have been executed at a cost of about 14*s*. per lineal foot in the neighbourhood of London. These sewers were built half a brick in thickness and in cement throughout, and the cost included excavation and refilling the soil.

300. Egg-shaped sewers formed according to the rule given (297), built half a brick in thickness and with inverts in cement, in an average excavation of 10 ft., may be estimated to cost per lineal foot as follow:—

	Ft.	In.		Ft.	In.		*s.*	*d.*	
Class	1—4	0	×	2	8	.	10	0	per lineal foot.
„	2—3	6	×	2	4	.	8	6	„
„	3—3	0	×	2	0	.	7	0	„
„	4—2	6	×	1	8	.	5	6	„
„	5—2	0	×	1	4	.	4	6	„

301. In forming the connections of drains with each other, viz., those of the house drains with the branch drains or sewers, and of these with the mains, through the several classes of sizes which it may be necessary to adopt, two rules should be in all cases imperatively insisted upon,—first, that all junctions shall be formed with curves, and of as large radii as possible in the direction of the current; and, secondly, that wherever a minor drain discharges into a larger one, the bed of the former shall be kept as much as possible *above* that of the latter as the relative sizes of the two sewers will admit.

302. The importance of the first of these rules has been long recognised and admits of proof, both theo-

retical and practical. It is found that in a sewer of 2 ft. 6 in. in width, a stream of water, flowing with a velocity equal to 250 ft. per minute, meets a resistance in suffering a change of direction, the amount of which depends upon the directness with which that change is made; the resistance occasioned being three times as great by a right angle as by a curve of 20 ft. radius, and double that produced by a curve of 5 ft. radius. The resistance thus diminishes as the radius of curvature of the junction is increased. The effect of junctions in which considerable resistance is opposed to the free passage of the sewage is, that the solid particles become deposited, and, being left by the flowing water, they accumulate until a bar is formed, which still further impedes the progress of the sewage, and eventually arrests it altogether.

303. The practical value of keeping the mouths of minor sewers above the level of the bed of the mains into which they discharge, arises from the prevention by this means of a return of the sewage up the minor drains, supposing a deficient declivity or any untoward circumstance should produce a retrograde movement within the main. The connection should also be formed in the most perfect manner, so that the mingling of the currents shall not have the effect of impeding either of them. The mouth of the minor drain should be spread into a bell-form, and the whole surface of the junction made solid and even with good cement.

304. The upper connections of the minor sewers, viz., with the house drains, are small works requiring the greatest care and circumspection. They are frequently disregarded and carelessly executed because they appear individually trivial matters; and, moreover, are troublesome and tedious, and correspondingly expensive. But it is clear that the efficiency of the entire arrange-

ment of any system of town drainage is primarily dependent upon the completeness with which the individual drains of houses convey the separate contributions of sewage into the minor or branch drains. If these tributaries fail the trunk of course remains idle, and all care bestowed on the larger works is thrown away. Supposing the house drains to be formed with clay or stoneware pipes, and the receiving branch sewer to be of the same material, lengths of the latter should be introduced at intervals having sockets into which the ends of the house drains may be fitted. If the branch sewer be of brickwork, the junction of the house drains should be carefully made good with a ring of cement, and the work nicely finished on the interior surface. It will of course be necessary to lay these house drains and branch sewers at the same time (if the latter are of brickwork and not large enough to admit a workman), in order to complete this work in the best manner. And as this is not always convenient, the stoneware pipes offer the great advantage of jointing without any hand work inside the branch, by simply laying the branch sewers with sufficient socket outlet lengths at intervals, which may be communicated with by house drains at any future time, the sockets being temporarily plugged up with wood.

305. The lower ends of the main sewers will communicate with the receiving wells, and should be well lipped downwards to promote the ready discharge of the sewage the moment it arrives at the mouth. These being principal works and few in number are more likely to be well attended to and carefully executed than the multiplied minor connections. The wells, adapted in capacity to the quantity of sewage they are intended to contain, will require substantial and sound work.

Being in towns necessarily sunk to some depth in the ground, the cylinder will be the best form in which to construct them. Behind and around the brickwork a backing of concrete should be filled in, the excavation being made sufficiently large for this purpose, and the whole interior surface should be lined with cement or asphalte. If this be done it will not be necessary to build the work in cement, although this would perhaps be a wise additional precaution. Proper economy in this matter will be best arrived at by experiments, upon which an adequate sum of money would be well expended before extensive operations are commenced.

306. Means of access to the main sewers are best afforded by side entrances, such as those which have been introduced in the Holborn and Finsbury division for the purposes of inspection and flushing. Although, if the entire system were properly constructed, no necessity could occur for artificial cleansing, it will be desirable to provide means of getting at the interior of the main sewers at intervals, and the side entrances referred to are well adapted for this purpose. The side entrance consists of a vertical square or rectangular aperture, formed in brickwork, and covered by a hinged iron cover, fitted in the foot-pavement of the street. This aperture is carried down to a level of about 2 ft. above the bed of the main sewer, and terminates in a short passage or tunnel, which opens into the side of the sewer. The vertical entrance is provided with hand-irons, built into the wall, by which descent and ascent are rendered easy.

307. We have already insisted on the necessity of so arranging and constructing the sewers of a town that they shall not require any cleansing by hand, and have denied the condition of admitting workmen as an essen-

tial one in determining the size of sewers. A sewer cannot be considered as properly constructed if it retain the matters committed to it in a quiescent condition. It should act simply as a place of passage, and instantly transfer the sewage onward towards the receiving well. Failing in this purpose, and containing all the solid matters in a constantly growing accumulation, the sewers of a town act as combined cesspools, and the several gully-holes serve as the outlets for the escape into the atmosphere of some of the deadly gases constantly engendering below. The expense of cleansing by hand is, moreover, an item of considerable importance, although, of course, never incurred until the subterranean nuisance becomes intolerable. In the Holborn and Finsbury division, the cost of removing the soil from the sewers provided with man holes is about 7*s.* per cubic yard, and from those without, 11*s.* per cubic yard, including the expense of breaking the arch and making it good again.

308. The method of cleansing the sewers in which matter accumulates, by flushing water through them, was practised to a great extent in the Holborn and Finsbury division of sewers, and has been adopted by the New Metropolitan Commission of Sewers. The principle of this method consists simply in retaining the sewage water for a period of time by flushing gates fitted in the sewer, and periodically admitting the accumulated water to pass by opening the gates, and thus producing an artificial rush sufficient to carry all accumulations before it. The relative economy of the process, as practised in the Holborn and Finsbury division, and, as compared with the hand cleansing, was stated as follows:—

	£	s.	d.
Washing away 6688 cubic yards of deposit by board-dams (a process always performed preparatory to fixing and using the flushing apparatus) . . .	644	12	7
Putting inside entrances and flushing gates	1293	0	0
	£1937	12	7

The cost of removing these 6688 cubic yards by hand would have amounted to 2387*l.* The preliminary cleansing and providing flushing apparatus were, therefore, effected at a saving of 449*l.* 7*s.* 5*d.* The current expenses of the two methods are thus stated:—

	£	s.	d.
Annual cost of cleansing 16 miles of sewers by hand	326	17	0
Annual cost of cleansing 16 miles of sewers by working flushing gates	106	0	0
Annual saving by flushing method .	£220	17	0

The cost of this method, as subsequently practised under the New Metropolitan Commission of Sewers, has been reported as being about one-third that of cleansing by hand; thus 22,400 ft. of sewers, in which the deposit varied from 6 in. to 3 ft. 6 in. (in depth) were cleansed, and 3386 double loads washed away at an expense of 500*l.*, which process, under the old system, would have cost 1500*l.*

309. The method of flushing is attended with one, and that a very serious, evil consequence, and the mischief of which is the greater in proportion to the force and velocity, and corresponding efficiency of the process. This is the violent driving forward of the foul

gases with which the otherwise vacant portion of a sewer holding stagnant refuse is usually filled. The flushing of the higher part of an extended line of sewer is thus frequently productive of a rising of these gases into the house-drains connected with the lower portion of the sewer, and any imperfection in the trapping of these admits the most noisome effluvia into the houses, while the streets are always poisoned with the gases thus driven up through the gratings and gully holes. Sometimes, indeed, the flushing water is forced into the house-drains, and, of course, occasions a total suspension of the flow of the sewage in the reverse direction. Accordingly, we find that the process of flushing has been discontinued during the warm season, the very time when it is most needed as an artificial means of cleansing the sewers.

310. For the efficient cleansing of the streets and thoroughfares of a town two provisions are requisite, viz., an abundant supply of water for occasional application, when the self-supply of rain is suspended, and a complete arrangement of sewers through which to discharge all the surface-water when its purpose of cleansing has been fulfilled. For the supply of water, the system of constant supply affords the greatest facilities, giving an instant command of the required quantity.

311. It has been ascertained in London, that one ton of water is sufficient to lay the dust over a surface of 600 square yards of gravel or macadamized roads, or of 400 square yards of granite paved streets. The average number of days per annum in which it is found, from twenty years' experience, to be necessary to apply water for this purpose, is about 120. The common charge for this work is at the rate of $\frac{3}{4}$*d.* per

square yard for the season, the water being applied only once per diem, or *50l.* per mile of a main road. The common assessment per house for watering roads twice a day is *1l.* for the season. The cost of doing the same work by means of jets, supplied from the main water-pipes, is estimated at *5s.* per house. At Nottingham, where the constant service of water is rendered, a charge of *7s. 6d.* per annum is made for a single street plug, by which some of the proprietors of shops command a ready supply, at all times, for watering the street in front of their own premises, and often of the adjoining houses also.

312. The scouring effect of jets of water thrown upon the surface of the streets is far greater than when merely dropped or thrown from the perforated pipe of a water cart. A single jet, supplied with a force equal to throw the water vertically upward to a height of 50 feet, will, directed at an angle of 45°, command an area of about 2000 square yards, and this surface will be really cleansed by the process, whereas the mere distribution of the water, without pressure, wets without cleansing. The mud which is formed on the surface of the streets, during certain states of the weather, is well known to have an unctuous character, which resists all cleansing action less vigorous than that of jets of water under pressure.

313. The position of the main sewers beneath the streets of a town affords ready means of directly discharging the waste waters from their surface. The adaptation of the sewers for this purpose requires inlets, at intervals, fitted with iron gratings, by which large substances are prevented from passing into the sewers. These inlets and gratings being situated at the sides of the carriage-way, while the sewer is beneath the middle

of it, they communicate by means of transverse drains or passages, which should be formed with sufficient declivity to prevent any accumulation of surface-water or road-sweepings beneath the gratings. The narrower the interstices between the bars of the gratings are the better. Very small spaces will suffice to admit the water with great rapidity, and also the mud which is formed upon the surface of the streets, and the narrow spaces are useful in preventing the admission of these matters during heavy showers with a force which might endanger the safety of the sewers.

SECTION V.

Conveyance of Water.—Piping, Aqueducts, Reservoirs.—Pumping Apparatus, Steam Draining and Pumping, &c.

314. For the conveyance of water from upper surfaces and sources to towns, open channels, or aqueducts, sometimes afford cheaper means than the laying of piping beneath the surface of the ground. In supplying water from these sources to some of the towns in Scotland, Mr. Thom has had occasion to construct several miles of aqueducts, and in preference to adopting direct lines, which are commonly obtained at great cost in the necessary aqueduct bridges for crossing valleys and other expensive works for meeting the difficulties presented by the natural ruggedness of the country, Mr. Thom designs his aqueducts by winding along the slopes, however circuitous the course thus involved, and descending only with such a fall as will allow the water to flow with a gentle current. Aqueducts thus formed are simply artificial rivers, and the entire expense is limited to that of constructing suitable banks and bed for the channel. An aqueduct thus constructed

at Greenock, passes through very rugged ground, and has cost not more than 400*l*. per mile. The New River, by which a large section of London is supplied with water from the springs of Chadwell and Amwell, with an additional supply out of the river Lea, near Chadwell, in Hertfordshire, is a fine example of an aqueduct of this kind. This channel, the enterprise of Sir Hugh Middleton, was commenced in 1609, and completed in 1613. The direct length between its extremities is about 20 miles, but its actual length is 39 miles. The average annual quantity supplied by this aqueduct is 614,087,768 cubic feet. Deducting from this the larger consumers and street-watering, together about 33,529,400 cubic feet, the remaining 580,558,368 cubic feet per annum are equal to about 46½ cubic feet per tenement, supplied each alternate day. The reservoirs, in which this supply is stored, are equal to contain the quantity consumed in seven days or 11,774,000 cubic feet.

315. The city of New York is partially supplied with water from the Croton river by an aqueduct 40 miles in length. The receiving reservoir of these works contains 150,000,000 gallons, and the distributing reservoir 21,000,000 gallons. The supply is effected without either pumps or water-wheels. An interesting work of this kind, a suspension aqueduct, has been constructed for a canal over the Alleghany river at Pittsburgh. This aqueduct consists of seven spans of 160 ft. each, from centre to centre of pier. On the piers are pyramids rising 5 ft. above the level of the side walk and towing path, and measuring 3 ft. by 5 ft. on the top, and 4 ft. by 6 ft. 6 in. at the base. The two wire cables which support the structure are placed one on each side. Each is 7 in. diameter, perfectly solid and compact, and constructed in one piece from shore to shore, 1175 ft. long,

of 1900 wires of $\frac{1}{8}$ in. thickness. Each wire is varnished separately, and the whole cable has a close, compact, and continuous wrapping of annealed wire laid on by machinery. Transverse beams of timber, 27 ft. long and 16 × 6 in., are placed in pairs at 4 ft. apart. Each pair of these beams is supported on each side of the aqueduct with a double stirrup of $1\frac{1}{8}$ in. round iron, mounted on a small saddle of cast iron, which rests on the cable. Into these beams wooden posts, 7 × 7 in. at top, and 7 × 14 in. at bottom, are mortised. These posts are the side supports of the water-trunk, which is of wood, 1140 ft. in length, 14 ft. wide at bottom, and $16\frac{1}{2}$ ft. wide at top, and $8\frac{1}{2}$ ft. deep. The sides and bottom are composed of a double course of $2\frac{1}{2}$ in. white pine, placed so that each course crosses the other diagonally at a right angle. The extremities of the cables do not extend below the ground, but are connected with anchor-chains which, in curved lines, pass through the masonry of the abutments. The bars of these chains average $1\frac{1}{2}$ × 4 in., and from 4 to 12 feet in length. They are formed of boiler scrap iron, and forged in single pieces without welds. The extreme links are anchored to cast-iron plates 6 ft. square. The total length of each cable and its chains is 1283 ft., and the weight of both cables 110 tons. The weight of water in each span (4 ft. deep in the trough) is 295 tons. The total solid section of anchor chains is 72 superficial inches. Deflection of chains, 14 ft. 6 in. Elevation of pyramids above piers, 16 ft. 6 in. The tension of each wire is 206 lbs., while its ultimate strength will be 1100 lbs.

316. Cast-iron pipes are now universally employed for the conveyance of water. They are formed with socket ends, so that all necessary motion is permitted

according to the expansion and contraction of the metal, caused by variations of temperature. Until the commencement of the present century all the water supplied by companies to London was conveyed in pipes bored out of elm, and at that time the New River Company had 400 miles of these wooden pipes in use. The general use of water-closets among the higher class of tenants, about the year 1809, led to the projection of new companies, who undertook to meet the growing want of water-supply at high service, by the use of steam power and iron pipes, a duty for which the old wooden pipes were inadequate. The bore of the wooden mains was from 6 to 7 in., and of the service pipes, 3 in. The principal iron mains now vary from 12 to 30 in. in diameter; the sub-mains are 6 and 7 in., and the service pipes usually 4 in. The interior of the cast-iron pipes used for conveying water should be coated with a preparation of lime-water to prevent corrosion and the consequent injurious effect upon the quality and flavour of the water.

317. Several methods have been adopted for forming the joints of iron water-pipes. Originally they were formed with flanges screwed together, but these were rapidly destroyed by the variations in the total length of piping produced by changes in temperature. Socket joints were then introduced, the joining parts being so formed that an annular space is left within the socket, and outside the entering pipe, for a ring of solder to be poured in for the purpose of making the joint water-tight. An improvement has been effected in this kind of joint, by making the parts to fit each other, and turning them accurately to a conical form, so that a water-tight joint is produced without any stuffing or packing of any kind, a little whiting and tallow only being used to assist the

close adhesion of the parts. This kind of joint is so perfect that it has been adopted in forming the joints of a steam-engine suction pipe, 30 in. in diameter, with perfect success. Wooden plugs of suitable taper form have also been successfully and economically applied for forming the socket joints of water-pipes prepared with an annular space, in which they are driven.

318. The weights of cast-iron pipes, as applied for water-supply, are as follows, according to the size or diameter of the bore.

In.		Cwt.	qrs.	lbs.	
3	diameter of bore	0	3	14	Weight of each pipe measuring 9 ft. in length.
4	„ „	1	0	14	
5	„ „	1	3	0	
6	„ „	2	2	0	
7	„ „	3	0	0	
8	„ „	4	0	0	
9	„ „	4	2	0	
12	„ „	6	0	0	
20	„ „	12	2	0	
36	„ „	34	0	0	

319. In determining the proper size for pipes, according to the quantity to be conveyed the following formula has been employed—

$$\frac{1}{15}\sqrt[5]{\frac{q^2 l}{h}} = d$$

in which q represents the number of gallons to be delivered per hour, l the length of the pipe in yards, h the head in feet, and d the diameter of the pipe in inches. In applying this formula Mr. Hawksley, Engineer to the Trent Water-Works Company, calculates that for supplying a street of 600 yards in length, the total length should be divided into three spaces of 200 yards each, and the quantity allowed for each of these spaces should be respectively as follows :—

		Gallons per diem.
Final 200 yards	. . . .	13,000
Middle 200 yards,	11,000 + 13,000 =	24,000
First 200 yards,	8,000 + 24,000 =	32,000

The calculation also assumes that the delivery of these entire quantities will take place in four hours, and that the whole of the water taken off from each length has to be passed to the end of that length. The delivery of these quantities respectively will require, according to the formula quoted, pipes of the following sizes :—

	Inches.
For the first 200 yards . . .	5·2 diameter.
„ middle 200 yards . .	4·5 „
„ final 200 yards . .	3·6 „

to which, adding half an inch for possible contraction by corrosion, the practical diameters become 6 in., 5 in., and 4 in. respectively. The difference in the size of pipes needed for the intermittent and the constant supply systems is exhibited in the following comparative statement:—

	Periodical Supply.	Constant Supply.
Mains . .	20 in. diameter	. 12 in. diameter.
„ . .	7 „	. 5 „
„ . .	6 „	. 4 „
Service pipes	3 „	. 2 „

320. Of the cost of raising water with pumps worked by steam-engines exaggerated conceptions are frequently formed, and it is therefore desirable to collect the best evidence on this subject, from which it appears that this cost is really an insignificant item, when the expense of the power is fairly compared with the quantity of water raised. Mr. Wicksteed, Engineer to the East London and other Water-Works Companies, has

recorded statements on the cost of pumping water by steam power, from which the following particulars are tabulated.

	Quantity of Water Raised per Diem.	Height to which the Water is Raised.	Cost of Raising 1000 Gallons 100 Feet High.	No. of Gallons Raised 100 Feet High for One Penny.
	Gallons.	Feet.	d.	
1. A single pumping engine, by Boulton and Watt, in 1809, working 10½ hours per diem, 6 days per week, mean power 29½ horses . (Average of 2 years' working.)	612,360	100	·543	22,099
2. Two single pumping engines, by Boulton and Watt, in 1809, working 24 hours per diem, 7 days per week, mean power of each engine 30½ horses . . . . (Average of 10 years' working.)	2,922,480	90	·358	33,519
3. Two single pumping engines, by Boulton and Watt, one in 1816, and one in 1828, working 12 hours per diem, 7 days per week, mean power of each engine 76 horses . . . . (Average of 10 years' working.)	3,601,116	100	·333	36,036
4. One single pumping engine, by Harvey and Co., upon the expansive principle, in 1837, working 24 hours per diem, 7 days per week, mean power 95⅛ horses . . . . (Average of 4 years' working.)	4,107,816	110	·150	80,000

In all these cases the coals are taken at 12*s.* per ton, and all charges for working the engine, coals, labour, and stores, are included, but no charge is allowed for interest upon outlay, or repairs of machinery and build-

ings. To raise 160,000,000 of gallons 100 ft. high would cost according to the

1st statement	. . . .	£362
2nd ,,	. . . .	238
3rd ,,	. . . .	222
4th ,,	. . . .	100

321. Of the performance of Taylor's pumping engine, in use at the United Mines, Mr. Farey has made the following computation:—The average duty performed by this engine during the years 1841 and 1842 was equal to the raising of 95¾ millions pounds weight of water, 1 foot high, by the combustion of 1 bushel of coal. Each bushel of coal weighs about 94 lbs., therefore each lb. of coal consumed by Taylor's engine raises 1,000,000 lbs. of water 1 ft. high. The unit of horse power adopted by Mr. Watt., viz., a force equal to 33,000 lbs., acting through a space of 1 ft. per minute, is found to be half as much more as the average performance of a good draught horse working 8 hours a day, and 6 days a week. A steam engine which raises 94,000,000 per bushel (as Taylor's engine does) consumes only 1·98 lbs. of coal per hour for each horse power, which it exerts independently of overcoming its own friction, and that of the pumps. That is when it exerts a power equal to that of 100 horses, it consumes only 198 lbs. of coal per hour.

322. Mr. Hawksley has furnished a compendious statement of his experience in raising and conveyance of water for the town of Nottingham, to this effect:—"The cost of transmitting water to a distance of 5 miles, and to a height of 200 ft., including wear and tear of pumping machinery, fuel, labour, interest of capital invested in pipes, reservoirs, engines, &c.,

amounts to about 2½*d*. per ton." The same gentleman calculates the resistance from friction in conveying water in pipes according to the formula

$$p = \frac{q^3\, l}{140\, d^5}$$

in which p represents the horse-power necessary to overcome the friction, l the length of the pipe in inches, q the quantity of water to be delivered in one second in gallons, and d the diameter of the pipe in inches. For the transmission of 500 gallons of water per second, two mains, each of 60 in. diameter, would be required, and the resistance arising from friction in these mains, 25 miles long, would, according to this formula, require about 450-horse power. The power required to *raise* this quantity to a reservoir at a height of 220 ft. would amount to that of 2000 horses nominally. The total power required to raise and transmit a distance of 25 miles through pipes, 500 gallons of water per second would thus equal that of 2450 horses. These figures are sufficient to show that the cost of raising and transmitting water by steam power is so small in proportion to the quantity of water thus placed at our command, that a pure but distant source may generally be economically applied in preference to supplying an inferior quality of water from more proximate sources.

DIVISION III.

DRAINAGE OF BUILDINGS.

SECTION I.

Classification of Buildings.

323. The principal classes of buildings as subjects for water-supply and drainage, are—1, Dwellings; 2, Manufactories; and 3, Public Buildings. Each of these admits of several sub-divisions, which should be briefly enumerated, in order to indicate the extent to which they are recipients of pure water and contributors of refuse matters to the sum total of town sewage.

324. Dwellings are to be sub-classified according to the superficial area which they occupy, and the average number of residents whom they accommodate, and the arrangements to be provided for the joint purposes of supplying water and discharging sewage are required to be proportional to these two data combined. Upon the extent of area the quantity of rain water will depend, and this has to be entered in the account in two ways, first, as affording an integral portion of the supply, and secondly, as contributing to the sum of the sewage. The principal datum will be the number of persons for whom water is required in each dwelling, and each of whom will yield an average share of the refuse to be removed. The calculations of Water-Companies are usually based upon the rental paid for each house as an index to the consumption of water within it, and in this way they recognise an almost infinite number of classes.

It is clear, however, that the mere rental furnishes no exact criterion of the number of occupants of a house. Nor would the number of rooms in a dwelling show this with much more accuracy. On the contrary, it is well known that houses of small rental and comparatively few apartments are frequently receptacles of a greater number of human beings than the more costly and capacious habitations of the wealthy classes. Nevertheless, *it is a fact*, that with the present habits of the poorer sections of the population the rental is generally in approximate proportion to the quantity of water consumed—a fact to be accounted for only upon the recognised and deplorable principle that poverty and uncleanliness are mutual exponents and companions in the social condition of civilized beings.

325. We have estimated (217) 20 gallons as the average daily quantity for each inhabitant of a town, and have supposed this quantity to be sufficient to allow also for an ordinary proportion of manufacturing operations, for the supply of public buildings, and for the extinction of fires (214). This estimate is founded upon the experience had in several towns in which the supply is considered adequate. Reserving the details of the appropriation of this quantity for the next section, we now refer to this general estimate as the datum upon which the proper supply of water to dwelling-houses should be provided, and as being at least approximately correct, if the service be constant and proper inducements be offered to all classes to cultivate habits of cleanliness. We would, therefore, subdivide the First Class of Buildings or Dwellings according to the average number of occupants of each, and provide the means of water-supply and drainage accordingly.

326. The Second Class of Buildings or Manufac-

tories, including all consumers beyond households, admits of a subdivision according to the operations carried on. Chemical works, including those for dyeing, calico-printing, &c., rank high as consumers of water. Factories for the making of paper, distilleries, breweries, bakehouses, malting rooms, slaughter-houses, stables, &c., also consume large quantities. Steam-engines are among the wholesale consumers. The charges made by the Nottingham Trent Water-Works Company are worth quoting in reference to the consumption of water, as their supply is constant, and provides for high-service, the two essential conditions of a complete water-supply. The charges for house service (according to rental, varying from 5*l.* to 100*l.*) are from 5*s.* to 60*s.* annually, being 10*s.* for 10*l.* rental, 20*s.* for 23*l.* or 24*l.* rental, 30*s.* for 39*l.* or 40*l.* rental, 42*s.* for 60*l.* rental, 50*s.* for a rental from 71*l.* to 75*l.*, and 60*s.* for 100*l.* rental. The incidental charges are as follow:—

	s.	*d.*
Stable and one horse	4	0
Stable and more than one horse, for each horse	2	6
Cows, each	1	6
Warehouses—upwards from	5	0
Offices	5	0
Gardens	2	6
Private baths in dwelling-houses	10	0
Slaughter-houses	5	0
Water-closets in private houses	10	0
Water-closets in warehouses, &c.	20	0
Victuallers' brewhouses, two brewings per week	20	0
Ditto ditto less than twice per week	16	0
Pipe for watering street in front of private house	7	0
Boilers of high-pressure steam-engines, working 10 hours per day, per horse power	9	0
Lace-dressing rooms, per yard in length, single frames	0	9
Ditto ditto double frames	1	0
Bakehouses 5*s.* to	8	0
Malt-rooms, per quarter of malt contained in steeping cistern	2	6

	s.	d.
Water consumed in erection of new buildings, per yard superficial on plan of each story	0	1
Water consumed in erection of fence walls, per yard superficial	0	0¼
Mill-hands, for drinking and washing only, per individual employed	0	3
Workhouses, including baths and washing rooms, per individual on the average of the whole year	0	8

The supplies to dyers, &c., are estimated and charged for according to the size of the service pipes, by the following scale:—

Diameter of Pipe.	Estimated			
	Supply.	Charge.		
Inches.	Gallons.	£	s.	d.
½	50,000	1	10	0
⅝	100,000	2	12	0
¾	200,000	4	12	0
⅞	300,000	6	10	0
1	400,000	8	6	0
1⅛	500,000	10	0	0
1¼	600,000	11	12	0
1 and 1 in.	700,000	13	2	0
1⅛ and 1 "	800,000	14	10	0
1⅛ and 1⅛ "	900,000	15	16	0
1¼ and 1 "	1,000,000	17	0	0
1¼ and 1⅛ "	2,000,000	32	0	0
1¼ and 1¼ "	3,000,000	45	0	0

The waste-water from condensing steam-engines of 500 horse-power in the aggregate will amount to at least 1500 gallons per minute, or 3 gallons per minute per horse power.

327. Public buildings requiring constant service are to be divided according to the number of residents or persons to be supplied. Thus union workhouses, prisons, lunatic asylums, &c., are to be provided at the minimum rate of 20 gallons per diem for each occupant. Baths and washhouses require quantities in proportion to the

maximum number of bathers and washers. Churches, theatres, and other places of public congregation are to be supplied for cleansing purposes according to the cubic contents of each building. In the baths, it may be estimated that a bulk of water measuring 6 ft. in length by 1½ ft. in width, and 1 ft. in depth will suffice for the ablution of each person. This quantity of water will equal 9 cubic ft., or about 54 gallons. The cost of supplying 1000 gallons by the Nottingham Trent Water-Works Company is, as we have seen, (paragraph 253) 2·88*d.*, or nearly 3*d.*, and, as this quantity will be adequate to supply about 19 baths, the expense of water per bath will be something less than one-sixth of a penny. The expense of fuel for heating 100 hogsheads of water,—sufficient for 100 of these baths,—from a medium temperature of 52° or 98°, including the replacing of heat lost by radiation, evaporation, and conduction may be taken at about 540 lbs. of Newcastle coal, which at London prices may be averaged to cost 6*s.* The cost of heating each bath will thus amount to about ·75*d.*, and including the water, ·916*d.*, or less than 1*d.* If as much more be added for attendance, and a similar amount for interest on capital in building, and for incidentals, it appears that a hot bath may be well afforded at a charge of 3*d.*

SECTION II.

Supply of Water Levels.—Constant Service.—Quantity required.—Cisterns.—Reservoirs.—Filters.—Valves and Apparatus.—Piping, &c. &c.

328. The relative levels at which water is required to be supplied to buildings in a town will necessarily govern the height to which the main quantity must first

be raised. But, practically, as the entire arrangements of the supply should be devised to command delivery at and above the most elevated of the buildings, the heights at which the delivery actually occurs will be found to affect only the current cost of raising, or the duty to be exacted from the power employed. And if this power be derived from steam-engines its cost will appear to be insignificant in comparison to the space through which the water is raised. The expense of raising 1000 gallons to an average height of 80 ft. is found by the Trent Company to be, excluding interest on capital, less than 1½*d.*, and the cost, according to Mr. Wicksteed's statement (paragraph 320), of raising 1000 gallons to a height of 100 ft. with a single pumping engine on the expansive principle, excluding interest on capital and repairs of machinery, is less than one-sixth of 1*d.*, or ·15*d.* Although the first cost of engines and pumping machinery of this class is very heavy, it will be a liberal allowance to balance this with the remaining ·85*d.*, and we shall then have an average current cost of 1*d.* for raising 1000 gallons to an elevation of 100 feet. From this it will be readily inferred how small a difference will arise from diminishing or increasing this height to the extent of 20, 50, or 100 ft.

329. The necessity for constant service, great as it is in all buildings, is still more imperative in supplying those of which the demand is of a variable character. In certain seasons, when the occasion for repeated bathing of persons and cleansing of apartments is greatest, these duties require a much larger quantity of water than will suffice at other periods, and this demand of course increases in the same ratio with the number of persons and apartments to be supplied. Thus workhouses, prisons, and all public asylums vary conside-

rably from time to time in the quantity of water required, and all methods of supply, short of constant service, and all provisions for storage fail in one way or another in securing the constant and unlimited command of fresh and pure water. Thus house-tanks, cisterns, and reservoirs, however capacious and well designed, serve to receive only limited quantities, and if these be ample for all purposes, it follows that if the consumption be lessened the greater quantity of water will remain in a stagnant condition, to be added to but not replaced by the next delivery from the main. The lower body of water in the cistern will thus remain slightly changed, and stirred up only, and in this way a lower bed of impure water, surcharged and rendered heavy with deposited matters, gradually accumulates, suffering a slow diminution by the proportion of impurity which it imparts to each portion drawn off for immediate use. *Pure* or *fresh water* is by this arrangement put altogether out of the question.

330. In large public asylums, properly constructed, arrangements would be made for supplying a bath at least once a week for every inmate. For this purpose an institution having 1000 residents would require weekly 54,000 gallons, or about 6000 cubic ft. of water. And if the supply be derived by a daily delivery, and the bathing be divided equally over 6 days in the week, a tank to hold the quantity for bathing only must have a capacity equal to 1000 cubic feet, or of the minimum dimensions of 20 ft. in length by 10 ft. in width, and 5 ft. in depth. The other purposes of cleansing would require (allowing 20 gallons per diem for each individual) 66,000 gallons weekly, or 11,000 gallons daily, and a tank to be daily emptied and refilled of the capacity of about 2000 ft., or measuring say 20 ft. in width and length, and 5 ft.

in depth. For contingencies, provision should be made for about half this quantity in addition, and thus the entire capacity of the tanks should equal 4000 cubic ft., or dimensions of 80 ft. in length by 10 in width and 5 in depth. And if the consumption one day be reduced one-fourth, and the tanks be not emptied before the fresh delivery, which it is practically impossible to effect,—this quantity of stale water will remain in the lower part of the tanks, and each day's reduced consumption will tend to increase the impurity of the water, unless duplicate tanks be provided, and a large amount of water be wasted in their periodical cleansing.

331. In cases where the constant service of water cannot be obtained, and it consequently becomes necessary to provide cisterns for buildings, they should be so constructed and furnished as to combine the operation of filtering with the purpose of storing the water. For this purpose the best form of cistern will be that of which the bed inclines downwards, so that the discharge pipe may be inserted at the lowest point, and the water always drawn from that part of the cistern. The material used being commonly slate, the bottom may still be formed in a single slab for house cisterns (so as to avoid extra joints), declining in both directions. The filtering media, consisting of beds of sand and gravel of different degrees of fineness (as described in Part I., p. 40), will be arranged in horizontal layers, excepting the lower one, which will lie in the bottom of the cistern, and be dressed to a level on its upper surface. The head of the discharge pipe should be protected with a fine wire gauze cap to prevent the gravel washing into the pipe. Below this pipe another cistern for the filtered water should be provided of proportionate capacity, and if the process be too tedious to admit of

the filtration of all the water used, that for inferior purposes may be drawn from a pipe entering the cistern just above the filtering beds.

332. The superior quality of rain water in respect to its softness, as compared with water from all other sources, renders it exceedingly desirable in an economical view, that all the supply desirable from this source should be carefully collected and preserved. In towns this water is commonly wasted, or at least allowed to subserve only the inferior purpose of assisting the flow of the drainage. Yet the quantity which might by efficient arrangements be commanded of this superior water is by no means insignificant. The roof of a house of the average dimensions of 20 ft. square, presenting a plane surface of 400 square ft., receives at least 800 cubic ft. of rain water annually, or about 4800 gallons. If well constructed and capacious gutters are provided, this quantity may be collected with little loss from evaporation, and will form a reserve stock for such special household purposes as it is peculiarly adapted for. This quantity should be immediately received in a filtering tank, and the best available method be adopted of purifying it from the carbonaceous matters with which it becomes saturated in passing through a smoky atmosphere and flowing over roof-surfaces covered with a deposit of similar impurity. An economical and well-devised apparatus for effecting this purpose, and applicable to private and public buildings of all classes, is a desideratum yet wanting in the economical supply of water.

333. All valves and other apparatus for regulating the admission and use of water in buildings are required to be constructed in the simplest and most efficient and durable manner. Complicated contrivances are utterly

inadmissible to be entrusted to the ordinary carelessness and inattention with which these things are treated in separate households. Apparatus of costly construction will never receive the sanction of landlords, nor will temporary tenants incur the charge of expensive repairs, or devote regular attention to keep ball-cocks and similar appendages in working order. And in proportion as the rental of houses is less, these difficulties are increased. Landlords become more parsimonious, and tenants less interested and more neglectful. In this point of view the advantages of constant and high service are rendered more conspicuous than in its application to tenements of a superior class in which a higher rental enables the landlord to be liberal in the construction and appliances of the building, and the tenant shares his disposition to preserve their proper action in order to secure his own comfort and convenience.

334. If the rain-water be not collected for household cleansing purposes, it should at least be made as efficient as possible for scouring the house-drains. An apparatus for this purpose has been suggested by Mr. W. D. Guthrie, a gentleman who has paid much attention to the subject of town sewerage, and was one of the early advocates for the use of small tubes in substitution for the larger drains, constructed of brickwork, which were formerly prescribed by Commissioners of Sewers as the only form of channels which should be permitted access to their subterranean and gigantic sewers or extended cesspools. Mr. Guthrie proposed that the rain-water from the roof be conducted into a cistern, the lower part of which should be formed like an inverted cone, and fitted with a conical valve at the head of a pipe, discharging into the house-drain. This

conical valve is to be attached to a vertical chain above it, and connected with the short end of a lever to the other arm of which a cord or chain is fixed, and by which the valve may be occasionally raised from its seat, and the water discharged from the cistern into the drain-pipe with a force proportional to the quantity in the cistern. From the upper part of the cistern a waste pipe is to descend externally and communicate with the drain pipe below the valve, so as to prevent the cistern overflowing, in case the water accumulates faster than it is discharged, the lower end of the waste-pipe being trapped, to prevent the effluvium in the drain-pipe passing into the cistern.

335. One of the most important of the occasional services for which a supply of water is required for application to buildings is the extinction of accidental fires. For extensive buildings, such as warehouses, factories, and workrooms, tanks have been suggested, and, in some cases adopted, in which a considerable quantity may be constantly stored and ready for instant application for this purpose. This arrangement is, however, scarcely applicable for private buildings, and, where it is employed, the quantity commanded is of course limited, and can never be safely trusted to as affording an adequate supply for extinguishing the fire. In this application of water, again, the system of constant service offers great advantages. Thus, if the mains are kept always filled, an adequate supply is at all times at hand in every direction, and the grievous losses and dangers incurred by delay in obtaining water on these occasions are avoided.

336. The combination of high service with constant service in the supply of water also affords the means of

instantly applying jets of water upon the fire until the fire or pumping-engines arrive. These jets are thus available as substitutes for the engines, and the experiments made to ascertain the height to which a jet of water will rise from the main and service-pipes under a fixed pressure, have shown considerable facility in applying jets for this purpose and a corresponding efficiency in their action. The practical limitation to this mode of delivery appears to arise from the extent of supply required, the economy of the use of jets depending upon the amount of pressure that can be obtained, and the small number of jets which will suffice for the extinction of the fire. The available power in this case is found to decrease in proportion to the extent to which it is employed, and the loss by friction in the leather hose reduces the delivery, and, consequently, the height or force of the jet, 2½ per cent. for every 40 lineal feet of hose through which the water passes. The importance of the results of the experiments with jets here referred to will justify a brief account of them in this place. They were tried on the 31st of January, 1844, upon jets supplied from the mains and services belonging to the Southwark Water-Company, under a fixed pressure of 120 ft.

The first experiment was made over an extent of 800 yards of 7 in. main, which were connected with 500 yards of 9 in., this length being joined to 200 yards of 12 in., continued by 550 yards of 15-inch main to the great main leading from the Company's works at Battersea, the total distance from the works to the experiment being 5500 yards. The heights to which the water was thrown from 2½-inch stand pipes, with 40 ft. of hose and a ⅞-inch jet, were as follows:—

With 1 stand pipe the water rose			50 ft.	
„ 2	„	„	45	„
„ 3	„	„	40	„
„ 4	„	„	35	„
„ 5	„	„	30	„
„ 6	„	„	27	„

When all the fire plugs on the main were closed, except the first and one $2\frac{1}{2}$-inch stand pipe, and 160 ft. of hose with a $\frac{7}{8}$-inch jet applied, the water rose to a height of 40 ft.

The quantity of water delivered from the same (7 in.) main through one stand pipe, and different lengths of hose, was as follows :—

With 40 ft. of hose	96 gallons	in 59	seconds.
„ 80 „	112	„ 65	„
„ 160 „	116	„ 70	„
„ 40 ft. and $2\frac{1}{2}$-inch jet .	118	„ 27	„

The second experiment was made with a 9-inch main 1400 yards in length, joined to a 15-inch main of 1000 yards in length, and at a distance of 6650 yards from the works. The stand pipes used were $2\frac{1}{2}$ in., the hose 40 ft. long, and the jet $\frac{7}{8}$ inch, as before.

With 1 stand pipe the water rose	60 ft.
„ 2 „	imperceptible difference.
„ 4 „	45 ft.
„ 6 „	40 ft.

The quantity delivered with the same pipes, length of hose, and size of jet, being

With 1 stand pipe	114 gallons	in 64	seconds.
„ 4 „ „	115	„ 75	„
„ 6 „ „	112	„ 78	„

These experiments, with the two sizes of main-pipe, will indicate the rate at which the quantity is diminished by the friction of the water in smaller pipes, a result con-

firmed by another experiment made with the addition of 200 yards of 4-inch service and 200 yards of 5-inch pipe to the 9-inch main last referred to. The hose, 40 ft. long, and the jets $\frac{7}{8}$ inch, as before.

With 2½-inch stand pipe fixed on the 4-inch service near the 5-inch pipe, the water rose				40 ft.
With 2	do.	do.	do.	31 ft.
With 1	do.	fixed at end of service, or 200 yards from 5-inch pipe, the water rose		34 ft.
With 2	do.	do.	do.	23 ft.

The quantity delivered in each of these last four cases being respectively as follows:—

112	gallons in	82	seconds.
117	„	103	„
112	„	90	„
114	„	118	„

337. In an interesting paper by Mr. James Braidwood, upon the means of applying water for the extinction of fires, read at the Institution of Civil Engineers, it is shown that elevated tanks for a reserve of water for this purpose should be adapted to contain 176 tons of water for each fire-engine to be employed. This allows for six hours working of an engine having two cylinders of 7 in. diameter with a stroke of 8 in., making 40 strokes each per minute, and fitted to throw 141 tons of water in six hours, and allowing one-fourth for waste, the supply required will be as stated, 176 tons. In the case of a large building, provision should be made for working ten engines for this period, and the quantity required will be 1760 tons, or 63,360 cubic feet of water. From this calculation, it will be evident that the dimensions of the tanks would be enormous. If steam engines can be commanded upon the premises to maintain the supply through the mains, the reserve

may be reduced to a consumption for two hours, before the expiration of which time it may be expected that the engine could be got to work. This provision is such as may be supposed requisite in dockyards and for large stacks of warehouses, manufactories, &c.

338. In the town of Preston, the advantages of the constant and high service have led to the general use of jets and the comparative disuse of engines for the extinction of fires. For this purpose the hose is carried upon a reel, and should be fixed upon a light spring cart, by which the ladders may be also conveyed. The ladders are found to be invaluable appendages, for the economical application of the hose without the engines, because the higher the water is carried upward in the hose, that is, the higher the nozzle of the hose is placed the less is the resistance suffered from the atmosphere. If a jet forced by a pressure of 100 ft. attain a height of 50 ft. when delivered at the ground level, it will still attain an additional height of 20 or 25 ft., when the nozzle is carried up these 50 ft., and the discharge will then take place at a total height of 70 or 75 ft. from the level of the ground. And another advantage derived from carrying the hose as high as possible is, that of commanding a more effective discharge of the water than can be obtained when the direction of the jet is conducted on the ground.

339. The piping for the conveyance of water to buildings has to be graduated in capacity according to the quantity required, in the same way that the mains and service-pipes are proportioned to the extent of district and number of buildings they are intended to serve. In supplying towns with drainage water collected in high reservoirs, and thence conveyed by aqueducts to "distributing basins," Mr. Thom adopts a general system of piping, which is so arranged that the

water shall always flow within them in one direction, entering at the upper and passing to the lower end. At the lower end of each range of piping a cleansing cock is provided, by opening which occasionally any improper accumulation within the pipe may be removed. The pipes are kept constantly full, and laid at a minimum depth of 3 ft. below the surface of the pavement. In some cases, in order to provide very fine cold water to private houses, an iron cistern, to hold about 20 gallons, is sunk 8 or 10 ft. below the bottom of the cellar, and supplied with water through a small lead pipe entering it at the top, while the water is drawn off for use through another small pipe, inserted a few inches above the bottom of the cistern. It would appear, however, that the cleansing of cisterns thus situated must be a somewhat troublesome duty, and the means of regular access to a cistern so deeply sunk in the ground must involve a considerable additional expense in construction.

SECTION III.

Varieties of Manufactures and best available Methods of Draining.—Arrangement of Separate and Collective Drains.—Proportion of Area of Drain to Cubic Contents of Dwelling-Houses.—Fall of Drains.—Mode of Construction.—Connection with Main or Collateral Sewers.—Means of Access, &c. &c.

340. The several operations carried on within a building devoted to manufacturing purposes should afford the data upon which to determine the extent of drainage required, but the most ready way of estimating the amount of refuse waters produced, will be reached by assuming this to equal the supply of water rendered to the building. The application of the same rule to domestic buildings or dwellings admits of a more

exact calculation as to the capacity of drains required, but these must all alike be governed by the principle that ample capacity for immediate discharge is to be sought with due regard to the fact that all passages for the conveyance of liquid or semi-liquid matters are efficient in proportion to the narrowness of the surface over which these matters are required to flow. This is one of the most important results which recent inquiries have established. Sewers and drains were formerly devised with the single object of making them *large enough*, by which it was supposed that their full efficiency was secured. But sluggishness of action is now recognized as the certain consequence of excess of surface equally as of deficiency of declination. A small stream of liquid matter extended over a wide surface, and reduced in depth in proportion to this width, suffers retardation from this circumstance as well as from a want of declivity in the current. Hence a drain which is disproportionally large in comparison to the amount of drainage, becomes an inoperative apparatus by reason of its undue dimensions, while if the same amount of drainage is concentrated within a more limited channel, a greater rapidity is produced, and every addition to the contents of the drain aids by the full force of its gravity in propelling the entire quantity forward to the point of discharge.

341. There are four conditions which are to be regarded as indispensable in the construction of all drains from all buildings whatsoever. These conditions are—First. That the entire length of drain is to be constructed and maintained with *sufficient declivity* towards the discharge into the sewer to enable the average proportion and quantity of liquid and solid matters committed to it to maintain a *constant* and *uninterrupted*

motion, so that stagnation shall never occur. Second. That the entire length of drain is to be constructed and maintained in a condition of *complete impermeability*, so that no portion of the matters put into it shall escape from it. Third. That the head of the drain shall be so efficiently trapped that no gaseous or volatile properties or products can possibly arise from its contents. And, Fourth. That the lower extremity of the drain, or the point of its communication with the sewer, shall be so properly, completely, and durably formed, that no interruption to the flow of the drainage or escape shall there take place, and that no facility shall be offered for the upward progress of the sewage in case the sewer becomes surcharged, and thus tends to produce such an effect.

342. These conditions appear so simple in their statement, that we are disposed to regard them as self-evident necessities, yet an acquaintance with the details of house-drainage as commonly regulated reveals the fact that they have been generally neglected, and that at the best the attention they have received has been most unwisely crippled by considerations of cheapness in first cost at the expense of permanent economy and usefulness. Thus we know that house drains are frequently laid with very imperfect fall, not sufficient indeed to propel the matters sent into them except with the aid of gushes of drainage-water, that they are often composed of defective and carelessly built brickwork with wide joints of sandy mortar, that the head of the drain is commonly untrapped, and that the entire formation is badly designed and defectively executed. We will endeavour to show the arrangements by which the efficient action of the separate drains of houses and other buildings is most likely to be secured.

343. The utmost practicable declivity being obtained in the direction of the drain, the efficiency of its action will be further much controlled by the construction adopted and the kind of surface presented to the sewage. Any roughness or irregularity in this surface will of course impede the passage of the sewage, and hence arises the necessity for the greatest care in the construction, whatever the material and kind of formation. The first step in the arrangement is to collect the whole of the drainage to one point—the head of the intended draining apparatus, and the determination of this point requires a due consideration of its relation to the other extremity of the drain at which the discharge into the sewer is to take place. In buildings of great extent this will sometimes involve a good deal of arrangement, and it will, perhaps, become desirable to divide the entire drainage into two or more points of delivery, and conduct it in so many separate drains to the receiving sewer. The length of each drain being thus reduced to a manageable extent, the necessary fall will be more readily commanded, and the efficiency of the system secured.

344. The cost of constructing these minor works, and also the main sewers with which they are connected, is so enormously aggravated by the depth to which they are frequently laid in order to accommodate the basements of buildings, that for the sake of economy, basement-drainage should either be altogether abandoned or so modified that efficiency shall never be sacrificed in a vain attempt to reconcile the depth of the basement with the position of the sewer. In arranging the drainage of buildings, therefore, the head of the drains should be kept at the minimum depth

which will suffice to sink the construction beneath the surface. We have already (288) expressed a conviction, that a thoroughly perfect and economical system of town-drainage must recognise this as a leading principle, and under this conviction we could not be satisfied to admit the difficulty now experienced to be one which should encumber our proceedings so as to involve comparative inefficiency in action and extravagant costliness in construction and repairs.

345. Although it is not within our province in this place to discuss the governmental measures which would be required to authorize and direct such an adjustment of the details of private drainage as would be necessary to insure their conformity with the principle here advocated, we may be permitted to observe that this direction was, to a considerable extent, assumed and exercised by the old Commission of Sewers, who always declared their authority in prescribing the manner in which private drains should alone be allowed to communicate with the sewers under their jurisdiction. These prescriptions determined the rate of declivity, the relative levels, and the dimensions of the drains, and were enforced by the Commissioners' execution (by their contractors) of that portion of the work which joined with the sewers. The regulations enforced in the City of London (and which, from its independence of the new consolidated commission, are, it is supposed, still enforced) are based upon the following calculation, the stated principle being that "A house cannot be called effectually drained unless the water is taken away from the floor of its lowest story."*

* It should be borne in mind that this principle becomes impracticable if the lowest story of any house should, at the free will and option of its

	Ft.	In.
Take the least height which a basement story ought to be . . .	7	0
Thickness of a timber flooring on sleepers	0	9
Covering of the drain, say brick flat	0	2½
Height of drain inside	0	9
Current of drain inside the premises, say, 1 *in. to* 10 *ft.* for a house 50 ft. deep	0	5
Current outside the house, *i. e.* in the street	0	3
Height of cross-drain above the bottom of main-drain, at least .	0	6
	9	10½

This would give (9 ft. 10½ in., or) 10 ft., at the least, depth from the surface of the street to the bottom of a main drain (of 18 in. diameter), and this may be fairly assumed as the least depth at which a private house of the most ordinary description can be effectually drained; but this considers it only as for the drainage of one house.

"When a series of houses, situate in a public way, inhabited by some who will use, and some who will not use, a drain fairly, is to be drained, the question has to be looked at differently.

	Ft.	In.
"For a retail shop, in which the basement story is often used as a warehouse, it cannot be unreasonable to say that the story shall not be less in height than	8	6
Flooring	0	9
Covering of drain	0	2½
Height of drain	1	3
Current inside	0	5
Current outside	0	3
Height above bottom of common sewer	1	6
	12	10½

"As it may be said that a story of less height might do as a wareroom, and, in order to keep the calculation

owner, have another "lower deep" excavated below it, a practice which has been indulged in in the formation of some of the leviathan warehouses in the City.

as low as it fairly can be kept, I would assume that the bottom of a common sewer ought not in any part to be less than 12 ft. beneath the surface of the street."*

We have thus quoted these calculations at length, in order that we may be enabled to refer to the details assumed without fear of mistaking the meaning of the official provisions of the Commissioners.

346. By another of the regulations of the Commissioners of the City Sewers, affecting the details of the house drains, we find that since the year 1832 the Commissioners have required that their own tradesmen should be employed to make the whole of the drains up to the front of the buildings, these drains, 15 in. in diameter, being charged at the rate of 5*s*. 6*d*. per lineal foot. And the reason alleged for this regulation was, that the Commissioners found great difficulty in getting individuals to make the drains substantially.

347. The regulations laid down by the Commissioners of Sewers for Westminster for the construction of private drains were as follows:—"That no drains shall be laid into a public sewer, without a special leave for that purpose from the Commissioners. That when such leave shall be obtained, the opening into the sewer shall be made, and the drain built, for a length of 3 ft. from the sewer, according to a plan and section approved by the Commissioners; the whole to be done by a workman to be employed by the Commissioners, and paid by the party requiring the drain, at the prices undermentioned:—For cutting through the springing wall of a sewer, putting in a cemented brick ring, and soundly underpinning the wall round the same, the sum

* "Memorandum," laid before the Court of Commissioners of Sewers for the City of London, &c., by their Surveyor.

of 10*s*. 6*d*. for each opening. For building a length of 3 ft. 4 in. of 9-in. barrel drain, with proper York keel stone, sound stock bricks and blue lias lime mortar, the sum of 10*s*. 6*d*. for each such length of drain. For the same length of 12-in. barrel drain, 12*s*. 6*d*. The digging to be done at the expense of the party requiring the drain; and notice to be given at the office of the Commissioners when the excavation shall have been made, in order that an officer may attend, and that a workman may be sent to do the required works. As a guide to persons about to build, it is recommended that the private drain of each house or other premises have a current not less than a quarter of an inch to each foot in length, making in the length of 60 ft. a fall of 15 in., to which, adding 13 in. for the height of the drain and brick arch over it, also 8 in. for the depth of ground and paving over the drain at the upper end, and 12 in. from the lower end of the drain to the bottom at the side of the sewer, will make, in the whole, 4 ft. from the bottom at the side of the sewer to the lowest pavement of the building, being the least height necessary to guard the premises from being flooded by water from the sewer."

348. These notices of the regulations which were enacted and enforced by two of the old Commissions of Sewers are sufficient to show that the powers which may now be required for instituting an entire system of house-drainage under public authority, or that derived from a Commission under the Great Seal, would be no new entrenchment upon private rights. The following order of the Westminster Commission declares its power to deny the right of draining into the public sewers if the depth of the building would require a rate of declivity less than then deemed necessary to insure

the proper action of the drain:—"The Commissioners give notice, that whenever the lower floors or pavements of buildings shall have been laid so low as not to admit of their being drained with a proper current, they will not allow any sewers, or drains into sewers, to be made for the service of such buildings."

349. The regulations we have quoted are, we submit, sufficient to show also that the details thus prescribed were not calculated to contribute to a system of efficient house-drainage, being inadequate, in some of the several indispensable conditions before stated (341).

350. Thus for cylindrical drains of 9 in. in diameter, a construction composed of the ordinary rectangular bricks, with mortar joints, is essentially unsuitable and imperfect, being unavoidably permeable to a considerable extent; the irregularities which occur at every joint, moreover, impair most seriously the effectiveness of the declivity which, if only 1 in. in 10 ft., or 1 in 120, as allowed in the City of London, is, even if fully preserved, inadequate for the purpose. The Westminster allowance of a quarter of an inch in each foot, or 1 in 48, is barely sufficient to make the rapid passage of the sewage a matter of certainty. And drains are much more likely to act efficiently if laid with a fall of 1 in 20 or 30. These regulations illustrate the two alternatives to which the present system reduces the practice and the utility of house-drains. In the one division we have an utterly inefficient declivity of 1 in 120, coupled with a *minimum* depth of 12 ft. for the bottom of the common sewer, while in the other division, the Commissioners, with an arbitrary kind of wisdom, decline to attempt the task of draining any premises with basements "laid so low as not to admit of their being drained with a proper current." The "propriety"

of the current would, however, be considerably enhanced by still increasing the fall of 1 in 48, which they adopted.

351. The common occupation of the basement stories of houses, as kitchens and water-closets, has made it appear desirable to depress the drains and sewers, in order to receive the refuse matters below the level of these basements; but as this object involves one or both of the evils we have pointed out, viz., deficient declivity and consequent stagnation in the drains, and a general system of sewers sunk so deeply in the ground that incomparable expense and difficulty are created in construction, access, and repairs, the purpose of basement-draining should be abandoned, and practicable methods sought of delivering the entire drainage at the level of the surface of the ground. If, indeed, no practicable methods could be devised of doing this so as to render basement-draining unnecessary, it must of course be admitted as part of the purpose of house-drainage, in order to avoid the sacrifice of the healthiness of human habitations, which we all readily admit as the final object of the art of draining towns and buildings.

352. The selection of the methods to be adopted for this purpose will be dependent mainly upon the internal arrangements of the building and the occupation of its lower apartments. In the first place, *water-closets must in all cases be constructed above ground,* or at any rate so nearly above, that the discharge shall take place within a foot or so of the surface. However valuable the ground-floor space of any premises may be, sufficient room may and always should be reserved for this purpose, as this level is the most desirable for

the situation of these accommodations. If placed higher, they cannot be so readily aided with the sewage water produced in the domestic offices, unless these occupy a similarly elevated position, and besides this objection, is that of having any unnecessary length or extent of drains above the ground. The most desirable arrangement, therefore, is that which collects the entire drainage at or near the ground level, and there at once and immediately delivers it into the subterranean channels. If, however, it is in any case unavoidable that the kitchen and similar domestic offices are situated in the basement of the building, it will be still equally imperative that all the sewage water shall be delivered into the drain at or near the ground level. No sink or other apparatus for discharging refuse water should be retained in the basement, and the extra labour of carrying this water up to the surface level, or head of the drainage, must be incurred as the penalty of this misconstruction or misappropriation of the building.

353. These arrangements, although involving expense in the alteration of some of the existing buildings in towns, are not to be magnified into impracticabilities. As essential parts of a general system conducive to the health of the entire population, they should be commanded and enforced by adequate public authority, and carried into immediate effect without favour or evasion. And in the construction of new buildings, they should be regarded as imperative general orders, sanctioned by the public well-being, and, if necessary, to be obeyed under official superintendence. The truth of principles and advantage of modes of action, established by experiment, should command their adoption without opposition, from the prevailing squeamish reluctance to

interfere with private arrangements, which, be it remembered, are, if misdirected, really in these matters public nuisances.

354. The keeping of the basement itself of a building dry by draining, is not, we submit, to be acknowledged as a proper purpose of a correct general system. Sufficient and sound construction are alone needed to maintain basement stories of any depth in a perfectly dry condition, if all sewage and rain-waters are, as they should be, collected and discharged into the sewers before they reach the basement. The draining of the surrounding subsoil to the entire depth of the foundation of a building is a want which cannot arise, if the entire structure up to the ground level is *waterproof*, which we contend it should be; the means of effecting this by the materials now at our command, being of economical and certain application.

355. Discarding brickwork and all similar constructions of small parts, as unsuitable for obtaining the impermeability and smoothness of internal surface which are especially required in small drains, the current in which is often reduced to a very small quantity of liquid or semi-solid matter, we are led to seek some tubes or pipes, which shall require only annular joining at distant points, and thus admit of the regularity of surface which is so necessary to assist the passage of the drainage. The stone-ware is now offered as a superior material for this purpose, admitting of much greater economy than iron, and being entirely free from the chance of corrosion and permeability. By glazing the interior surface, moreover, tubes of this ware are made peculiarly suitable for adoption in forming drains; and carefully-made socket joints laid in the direction of the

current are cheaply executed, if moulded conically and luted with a little cement of best quality.

356. The size of the drain-pipes has to be graduated according to the quantity to be passed through them, limited in the minimum extreme so as to avoid stoppage from the excessive bulk of the sewage matters, and in the maximum extreme so as to obtain all the rapidity of progress of which a small stream of water is capable, retarded by the friction of the surface over which it passes. For moderate sized houses, say of eight rooms, and holding some five or six persons on an average, a tube of 5 in. in diameter will suffice for the house-drain. The area of the drain may be proportional to the cubic contents of the house, but if so, in diminishing ratio. That is, if a 5-in. pipe will be large enough for an average sized house, a pipe of double the area of such a pipe will not be required for a house of double the cubic contents, or holding double the average number of persons. A 6-in. pipe, laid with sufficient fall, will be ample for the most capacious private house. And from 9 to 15 in. will, under a similar condition, be sufficient to serve the average drainage of factories and other large consumers of water.

357. The trapping of the head of the drain, so as to prevent the ascent of smell and impure gas from the drain into the building, is the next indispensable requirement in the draining apparatus. So many contrivances have been applied for this purpose, that we will not attempt to make a selection; and it is beyond our limits to give any general list or detailed description of them. Simplicity of construction and permanence of action are, of course, required, with the least original outlay at which these qualities can be obtained. If

only one water-closet is to be provided for, it will be desirable to gather the discharge from it and from the house-sink, &c., into one trap at the head of the drain. If two or more closets are to be served, so many separate traps will sometimes become indispensable. But for every separate inlet to the drain, which is equally an outlet for smell and gas, an efficient trapping apparatus of some kind is required.

358. The lower connection of the house-drain with the public sewer is the last point of importance to which we have to allude. A perfect construction of this portion of the work has always been recognized as an essential feature of good drainage, and the Commissioners have accordingly stipulated that its execution should be entrusted only to their own contractors, and be subject to the inspection and approval of their own officers. The level of the bed of the drain must be kept as high as possible above that of the receiving sewer. If the sewer be also constructed of the glazed stone-ware piping, lengths of it may be introduced at convenient intervals, having outlet sockets for receiving the ends of the house-drains, and those being slightly tapered or conical in form will be readily jointed with a little of the best blue lias cement or other of equal quality. If the sewer be constructed of brickwork, a good joint will be obtained by introducing a separate socket of stone-ware to receive the house-drain pipe, and formed with a flange at the other end to surround and cover the opening in the sewer, which can then be made good with a ring of cement carefully applied.

359. Means of access to house-drains are always desirable in arranging the details of the apparatus. And this constitutes another reason against the deeply sunk drains required to serve the basement story of houses.

If the drains be constructed of glazed stone-ware pipes, carefully jointed, and laid in directions as nearly uniform as possible, the process of artificial cleansing and raking (should it ever become necessary) will be much facilitated. If any angular turns are formed in the direction of the drains, it will be worth while to consider the practicability of fitting a moveable cover at the angle by removing which, direct access should be afforded to the two branches of the drain. A long pliant rod with a stiff brush or scraper at the end could then be readily ntroduced into the drain, and, if necessary, these means iof access by trap doors and removable covers should be afforded at intervals throughout each extended length of drain, so that thorough cleansing from the head of the drain to the outlet in the sewer could be performed as frequently as might be found requisite. Under a complete and efficient system of drainage the task of periodically examining the separate drains from the buildings would be ordered and performed with all the regularity and readiness of a necessary duty, and the drains would be maintained in a state of constant instead of intermittent cleanliness.

SECTION IV.

Water-Closets; Arrangement and Construction.—Adaptation to various circumstances.—Combined Arrangements for Efficient House-Drainage.—Miscellaneous Apparatus and Contrivances.

360. The best position for a water-closet in any building, is that in which all the waste water shall be made the best use of in scouring the contents directly through the pan of the closet, and propelling them forward through the private drain into the common sewer. And since the matters discharged into the closet will be,

if the house drain is reserved for its proper uses, more solid and less readily conveyed than the other sewage matters, it will, moreover, be desirable to place the closet as near as possible to the point at which the drain discharges into the sewer. The velocity and force of the liquid sewage are increased at the lower or sewer end of the drain, and its effect is thus augmented in scouring away the contributions of the closet. But if this preferable position cannot be commanded for the closet, it must at any rate be so situated with regard to the head of the drain and the inlet for the liquid sewage, that these shall be behind or above it. When the closet and the house-sink are near to each other, the water from the latter may be conducted directly into the trap or basin of the closet, and thus secure at once a rapid discharge of its contents and a constant supply of liquid to preserve its action and efficiency.

361. The rudest form of domestic accommodation or open privy over a cesspool is a contrivance which deserves notice only on account of its several imperfections, and which will, it may be hoped, be soon reckoned among the obsolete mistakes of our forefathers. These cesspools are sometimes mere pits or holes excavated in the ground, and the contents of course rapidly permeate the surrounding soil; by which process pits of this kind frequently are found to drain themselves, the perviousness of the material permitting the escape of the sewage, so that little accumulation takes place within the pit itself until the whole neighbourhood becomes fully saturated with the drainage, which will then ooze through and appear upon the surface, or find its way through some defective foundation, and poison the basement of an adjoining building. Constructed cesspools formed with brickwork of substantial quality will

prevent this saturation in proportion as their walls are carefully and imperviously built. The matters daily discharged into these depositories accumulate, and their decomposition is constantly proceeding and engendering gases of the most noisome and pestilential kind. The open privy formed over a pit of this description affords an outlet for the escape of these gases which are thus regularly supplied to the building above or adjacent to the closet. If a trap or water basin and pan be applied to this privy, so that the pan dips into the trap, the escape of effluvia may be prevented so long as the trap is kept supplied with water. The supply of water for this purpose will, however, considerably augment the bulk of the sewage, and necessitate cleansing much more frequently than otherwise, unless some defect in the joints of the work afford a passage for the liquid matters into the surrounding strata, or a communication be afforded with a drain. In this latter case of combination of a cesspool with a drain, a waste pipe may be laid from the former into the latter, so that the contents of the cesspool shall always be maintained at the same quantity and depth; the trap may then be dispensed with by attaching a vertical pipe to the lower part of the pan, so that this pipe shall dip into the sewage, and being thus constantly kept below its surface, no gas can pass upward through the pipe. The cost of the pan or basin and pipe required for this contrivance, if of stoneware, will not exceed 13*s*. in addition to that of a common privy, and its advantages in preventing the escape of effluvia are obvious. The simplest and cheapest form of trap and basin is that in which they are formed in one or two pieces of the stone-ware, and may be purchased at about 7*s*. 6*d*. together. Allowing 5*s*. 6*d*. for the fixing, and also providing and fixing a

short length of pipe of the same material to connect with the trap so as to dip into the sewage, this complete trapped apparatus may, at a cost of 13*s*., be added to a common privy over a cesspool, so as to prevent to a great extent the escape of effluvia into the house or adjacent building.

362. The great importance, however, of avoiding all sources of unwholesome and offensive effluvia, and of preserving the foundations of the buildings and the substrata of the soil of a town in a dry and clean condition, creates a severe necessity for relinquishing cesspools, and all *receptacles* for sewage, within or connected with all buildings and places whatsoever, except those to which it is conducted for the purposes of collection and treatment. *The sole purpose of all house apparatus of water-closets, sinks, and drains, and of all public constructions of branch or tributary sewers, and main sewers, should be that of affording a passage for the conveyance of the refuse waters and other matters produced in a town. This conveyance should be immediate, every particle committed to the entire ramification of passages being preserved in ceaseless motion until it arrives at the final collecting place.*

363. Discarding cesspools upon these grounds, we are at the same time led to the principle which should govern the whole of the details of house-draining apparatus, which should be so arranged and combined as to afford the fewest possible inlets for effluvia from the matters committed to the drains, and to make the total of the liquid refuse useful in advancing the current within the drains. The position of the water-closet being determined (360), it becomes desirable to select the most economical and efficient construction for it, and for the apparatus connected with it.

364. We have already (357) stated that the head of the drain, and every inlet to it, requires to be fitted with a trap to prevent the escape of effluvia, and this will equally form an indispensable part of the closet apparatus. The perfect action of the trap will demand a means of supplying water on each use of the closet, and although all possible advantage should be taken of the house-sewage water in promoting the action of the drains, a separate and constantly commanded source should be provided for this purpose. If the supply of water to the house or building be rendered upon the constant service system, a mere tap will be sufficient to afford the means of discharging a volume of water through the trap of the closet. If the water be supplied upon the intermittent system, a cistern or reservoir of some kind, provided for the house supply, must be made to communicate with the pan of the closet by a pipe with a valve and apparatus for working it. For general use it is especially desirable that economy and simplicity be combined in the whole of the apparatus of the closet. Delicacy of adjustment, requiring a complicated arrangement of parts, and a corresponding costliness of construction and repairs, and carefulness in management, is inadmissible in a design adapted for general adoption; and combinations of levers and cranks, liable to accidental derangement and injury by roughness of treatment, are therefore to be avoided as much as possible. The position of the cistern in relation to the closet will affect, in some degree, the force and efficiency of the volume of water discharged on each occasion; and, if the supply of water to the building be constant, the service-pipe should be so conducted over the closet that the tap can be conveniently placed for admitting the required quantity to the pan. If the

supply is obtained from a house-cistern, this must, of course, be placed above the pan, and at such elevation that the water may acquire a sufficient impetus to flow with rapidity.

365. The glazed stone-ware basins or pans, with syphon-traps combined, before referred to (361), are the most economical and effective for general purposes. These are made in several forms: viz., with the pan and trap in one piece, and adapted to communicate either with a vertical or a horizontal drain; with a separate trap, having a screwed socket on the head in which the lower part of the pan is received, being formed with a collar and screwed end; or, as a somewhat more complicated arrangement, consisting of a trap with a flanged head and a separate dip pipe having a projecting flange about its mid-length, and a spreading mouth above, into which the lower part of the pan is fitted with cement. The dip pipe, extending downwards into the trap, below the level at which its contents flow out, is secured to the head of the trap by bolts passing through the holes in the flanges. The reason for making the pan separate from the dip pipe would appear to arise from a difficulty in forming them together with the wide projecting flange so as to give sufficient steadiness to the pan above. This latter form was designed especially for prison use, under circumstances which do not allow of any fixed seat or framing above to which to secure the pan. The previous forms are found to answer all purposes in cases where this kind of support is afforded, and are preferable for their fewer number of parts. The pan in each of these forms of construction is provided with an aperture and inlet at the upper part, having a socket to receive the water-pipe. They are retailed at the price of 7*s.* 6*d.* each, and recommended by the present authorities in drainage matters.

366. The combined arrangements for efficient house-drainage comprise, besides the means of adequate water supply, as explained in Section II. of this Division, the water-closets, house sinks, and drains in which the matters committed to the closets and sinks are conveyed and delivered into the public sewers. And if the rain-water falling on the roof of the building and on the yard or space attached to the house, is not applied to any other purpose, it will have to be conducted into the drain to be discharged with the sewage. These waters being the purest of the contents should be received as near as possible to the head of the drain, and made to traverse its entire length, and thus exert all the cleansing action of which they are capable. The house sink or place at which the ordinary waste water of the household is discharged should communicate with the drain at a subsequent part of its course, and the closet be so placed that its contents shall traverse a minimum portion of the drain, thus reducing the liability to the escape of effluvia, and deriving the greatest scouring force from the accumulation of the rain and house waters. The drain being formed as a complete and impervious channel receiving the entire sewage and waste waters of the premises, made easy of access and examination, and provided with traps at every opening or inlet for receiving the drainage, may be graduated in size from the one extremity to the other, and if of considerable length, it may be provided at intervals with self-acting valves or traps to prevent the possible return of any matters, waters, or gases, from the lower towards the upper end.

367. Self-acting valves or traps are constructed of the stone-ware; and the valves being hung at a slight inclination, and well fitted with a rim on the meeting *surface, they* remain closed against any retrograde

movement of the sewage or gases, but are readily opened by a slight force of water in the outward direction of the drain. Sink traps are also formed of this material, with perforated heads or covers, and syphon bends below, which remaining filled with the drainage water, prevent the escape of any effluvia from the drain into which they give access.

368. Beside the socket drain-pipes of glazed stoneware which we have described, another material, known under the name of "Terro-metallic," has been applied in the production of a superior quality of piping, which is manufactured in cylindrical forms both with socket ends and plain butt ends, and also in a conical form with plain ends, the cones fitting one another so that the joints are similar to conical socket joints, and may be made to fit with a great degree of exactness. The material of these pipes is of the same quality as that used in making fire-bricks, and has an extreme density with a very durable glaze upon the surface. The prices of these pipes at the Tileries, Tunstall, Staffordshire, where they are manufactured, and in London, are as follows:—

TERRO-METALLIC DRAIN PIPES.

Diameter of Bore.	Plain Jointed Cylindrical Pipes.		Conical Pipes to Fit one another.		Cylindrical Pipes with Socket-Joints.	
	Price per Foot at Tunstall.	Price per Foot in London.	Price per Foot at Tunstall.	Price per Foot in London.	Price per Foot at Tunstall.	Price per Foot in London.
Inches.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
2	0 2	0 3	0 2⅜	0 3½	......	......
3	0 2⅝	0 4	0 3	0 5	0 3¾	0 5½
4	0 3⅜	0 5	0 3⅝	0 6	0 4½	0 6¾
6	0 4	0 6	0 4⅝	0 9	0 6	0 9
9	0 6	0 11	0 8	1 2	0 9	1 3
12	1 2	2 1½	......	......	1 4½	2 3
16	2 3	3 9	......	......	2 6	4 0

Curved and Junction pipes in the same material are charged at double the prices of the cylindrical pipes.

369. One of the most valuable improvements recently effected in the practical cleansing of buildings, is a portable pumping apparatus, with hose for emptying cesspools. For conveying the sewage, this consists of a close tank mounted upon two or four wheels, according to its size, with a hose fitted to an aperture in it, and an air-pump attached, so that the chamber communicates with the interior of the tank. The hose is provided of such length that it may be laid through the passage, &c. of a house, and dipped into the cesspool, while the other end is attached to the tank at the door, into which the contents of the cesspool are rapidly transferred, without offence or nuisance, by a labourer at the pump. A small pumping apparatus with hose, but without tank, has been extensively applied for removing the contents of the cesspools into the sewers, a second hose being attached to the pump chamber for this purpose. This apparatus, with hose complete, is furnished at the price of 15*l*., and the economy of its use as compared with the cost of cleansing cesspools by the old method, effects a saving of 95 per cent. Among the instances reported by the Surveyors to the Metropolitan Commission of Sewers, the following may be quoted:—"The contents of one large cesspool, equal to 24 loads of soil, were pumped out in 3¾ hours, at a cost of 24*s*. Under the old system three nights would have been occupied in emptying the cesspool, and it would have cost at least 24*l*."

370. Among the many contrivances which have been suggested for improving the house-apparatus for regulating the disposal of the water supplied, is a simple form of cistern, introduced by Mr. John Hosmer, which appears well calculated to prevent the waste of water which now frequently results from the inefficiency of the apparatus employed. The amount of this waste

may be inferred from the proved fact that, in one district of the metropolis, an average quantity of *twenty-nine* gallons per house is wasted at each delivery from the works, by dribbling over the waste-pipes of the cisterns after they have become filled. Mr. Hosmer's cistern has a partition, dividing it into two spaces, one considerably larger than the other, and containing the supply for domestic use, while the smaller space is intended to contain a reserve for cleansing the drains and sewers. A two-way cock is fitted on the cistern with ball and lever, and one aperture of the cock opens into each of the spaces in the cistern. The large division of the cistern is fitted with a pipe or pipes to deliver the house supply as required, and the small division has a syphon-trapped pipe, leading into the drain and covered by a valve, the vertical rod of which is attached to the lever of the two-way delivery cock. The water from the main first fills the small division, the position of the lever being such that the valve at the lower part remains closed. The water then flows over the partition (which is kept a trifle lower than the sides of the cistern for this purpose) and fills the large division, the rising of the ball in which overcomes the pressure upon the valve in the small division, and lifts it suddenly to such a height as to permit of a rapid discharge of water through the syphon-trapped pipe into the drain. Similar cisterns thus fixed and fitted, deriving their action simultaneously from the delivery at the main would, it is supposed, discharge streams of water at one and the same time into the several house-drains connected with them, and thus act with considerable efficiency in scouring these drains and the sewer into which they discharge.

371. Although complexity of parts is to be avoided

in water-closets intended for use in the greater number of dwellings, some of the more complete forms of apparatus adapted for self action, and which necessarily comprise considerable detail of arrangement, are preferable in superior buildings in which close economy of construction is not a first condition, and regular care and attention can be secured for the action of the apparatus employed. In some of these closets, the valve which opens and closes the opening into the water-pipe is attached by a rod to a lever, which, by means of a cord or chain, is connected with the door of the closet, so that the opening of the door opens the valve and thus discharges a quantity of water into the pan. In another form of apparatus, the pressure of the person on the seat produces a similar effect. One of the most improved of these is that patented by Messrs. Bunnett and Co., which will be found fully described and illustrated in the "Civil Engineer and Architect's Journal" for the month of April, 1849. This closet is self-acting and doubly trapped, and designed to secure a supply and force of water which shall always be efficient and uniform without waste. It is, moreover, so contrived, that no soil can remain in the basin after use, and an ample supply of water being secured in the basin so as to form a "water-lute" between that and the syphon-trap, the rising of smell is effectually prevented. The lower part of the pan dips into a water-pan or trap, which is hinged and maintained in a horizontal position by a rolling balance weight. The effect of pressure on the seat of the closet is to depress a lever and open a valve in the supply box of the cistern, and thus pour a volume of water into the water-pan or trap sufficient to throw it open, and thus afford a passage for the soil into the lower basin, which terminates in a syphon, and is also

trapped with water. When the pressure is removed from the seat, the water-pan or upper trap is immediately brought back to a horizontal position by the rolling weight, and receives sufficient water before the closing of the valve, to fill it, and thus effectually shut off all communication with the lower basin.

GENERAL SUMMARY AND CONCLUSION.

372. In the First Part of this Rudimentary Treatise, devoted to the Drainage of Districts and Lands, an attempt is made to exhibit an arranged outline of the facts which have been observed and recorded with reference to the several sources of water for agricultural purposes, and the best means of making these available. The methods of filtering and purifying water for extended purposes in districts comprising towns, are also briefly explained, and the difference pointed out between the mechanical and chemical processes required. In the sections which treat of the drainage of lands, as limited in its purpose to the discharge of superfluous water, the peculiar method to be employed is shown to depend on the united consideration of relative levels of surface and structural formation of soils. The importance of efficient draining of fens and the several works required for this purpose, are illustrated by grand instances in our own country—in the counties of Lincoln and Cambridge—and a brief description is introduced of that celebrated Dutch work by English Engineers, the draining of the Lake of Haarlem. The construction of catch-water drains, and the adoption of means for aiding the supply of water to high or upland districts, are also alluded to as among

the duties of the drainer. The formation of soils is described as affording a general knowledge of their character and aiding in the determination of the best arrangement of drains. Adopting a general classification of soils in regard to their structure, under the three leading characters of porous, retentive, and mixed, an extended notice is devoted to the several arrangements of these soils which are met with, and the modes of proceeding in each case are briefly explained. A description of the several modes of forming drains or artificial subterranean channels through lands is accompanied by practical rules as to their construction, dimensions, arrangement, and cost, and some of the best experience on this subject is quoted. A brief account of the several operations to be carried on, of contour-mapping, and of the tools employed in draining, completes the First Division of the work.

The Second Division, of which the purport is the Drainage of Towns and Streets, aims at establishing a classification of towns as subjects for water supply and drainage according to the relative levels of the surface, and without that reference to the contiguity of rivers which has been dictated by the mistaken object of converting rivers into general sewers. An illustration of the principle here advocated is taken from the position and superficial character of our own metropolis. The value of sewage matters for agricultural purposes, and the practicability of rendering the distribution and use of these matters innocuous by chemical processes, are also stated upon the highest authority, and the evils of concentrating the sewage of large towns at few points, and misusing the channels for its conveyance, are pointed out and established upon past and extended experience. A brief notice is added of some of the general plans

which have been suggested for the drainage of London, and some particulars given of the costly and inoperative works executed in the department of Metropolitan Sewerage. Upon the public supply of water to towns a mass of evidence is collected from past experience in the metropolis and the provinces, showing the effect of geological structure upon the quality of water, and the cost of supplying, of filtering, and purifying it for the several purposes required. The circumstances affecting the cleansing and draining of roads and streets are also shortly noticed. The proper functions of sewers, their arrangement, dimensions, and construction are deduced from the data which it is believed should be referred to, and by calculations which our past experience enables us to form. A rule for the correct sectional form of sewers is also given, and recommended for its usefulness and simplicity. The cost of several descriptions of sewers is also cited from the records of experience, the stone-ware pipe sewers described, and the method of cleansing by flushing adverted to, and its effects quoted. The conveyance of water to towns and the several methods adopted, with the cost of pumping by steam-power, are described and stated.

The Third Division treats of the Drainage of Buildings as subjects of the entire system which embraces the supply of water as an accessory to the purpose of draining. It is suggested that the classification of dwellings should be determined by the number of persons to be served rather than the rental paid for each house, and that larger buildings in which human beings are congregated for manufacturing and other purposes, may be provided for according to the cubic space inclosed by them. The arrangement, construction, and dimensions of house-drains are described, and the

qualifications of impermeability, secure trapping at the head, and all other openings through which effluvia might escape, and proper connection with the receiving sewer at the lower end, are insisted upon as indispensable to perfect and efficient construction. And in the concluding section a general view is taken of the combined arrangements for efficient house-drainage and the simplest construction recommended for water-closets and similar apparatus designed for general adoption.

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